EECE 5639 Computer Vision I

Lecture 4

Coordinate Changes, Photometry, Color

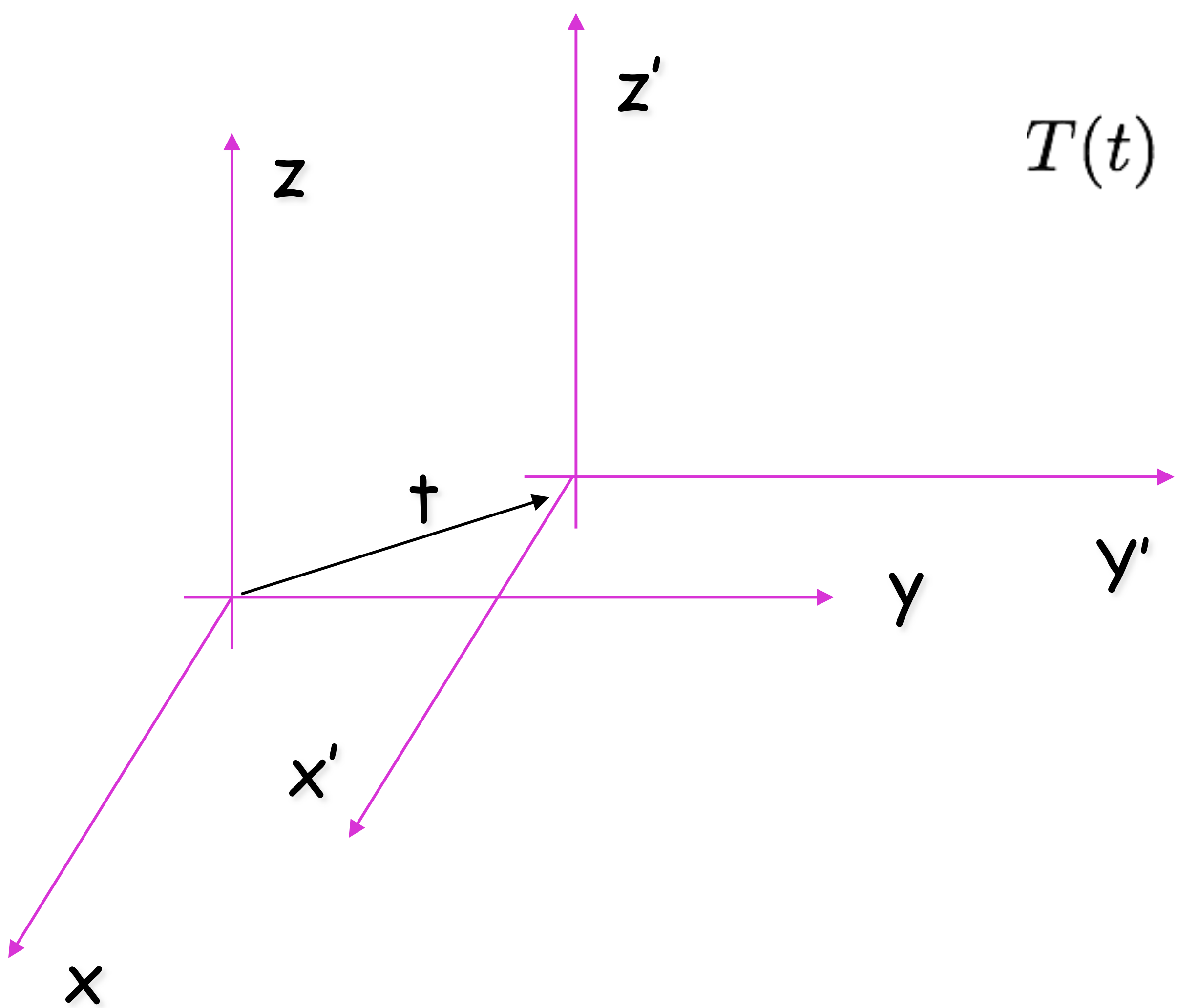
Next Class

Filtering

Northeastern University

3D Translation of Coordinate Systems

Translate by a vector $t=(t_x,t_y,t_z)'$

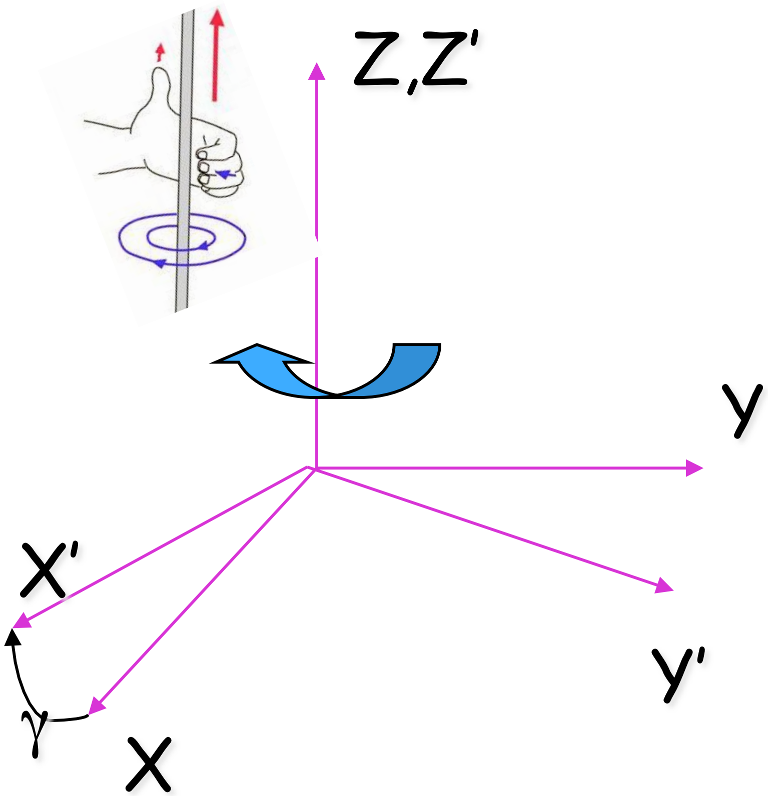


$$T(t) = \begin{bmatrix} 1 & 0 & 0 & -t_x \\ 0 & 1 & 0 & -t_y \\ 0 & 0 & 1 & -t_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} X' \\ Y' \\ Z' \\ 1 \end{bmatrix} = T * \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

3D Rotation of Coordinate Systems

CLOCKWISE Rotation around the coordinate axes (left hand):



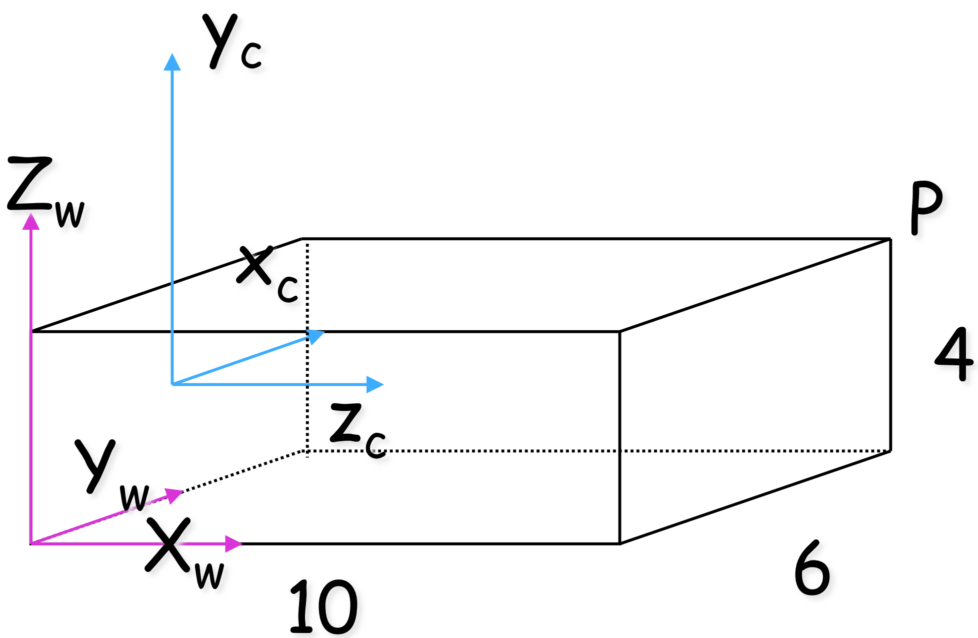
$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = R * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$R_x(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix}$$

$$R_y(\beta) = \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{bmatrix}$$

$$R_z(\gamma) = \begin{bmatrix} \cos\gamma & -\sin\gamma & 0 \\ \sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

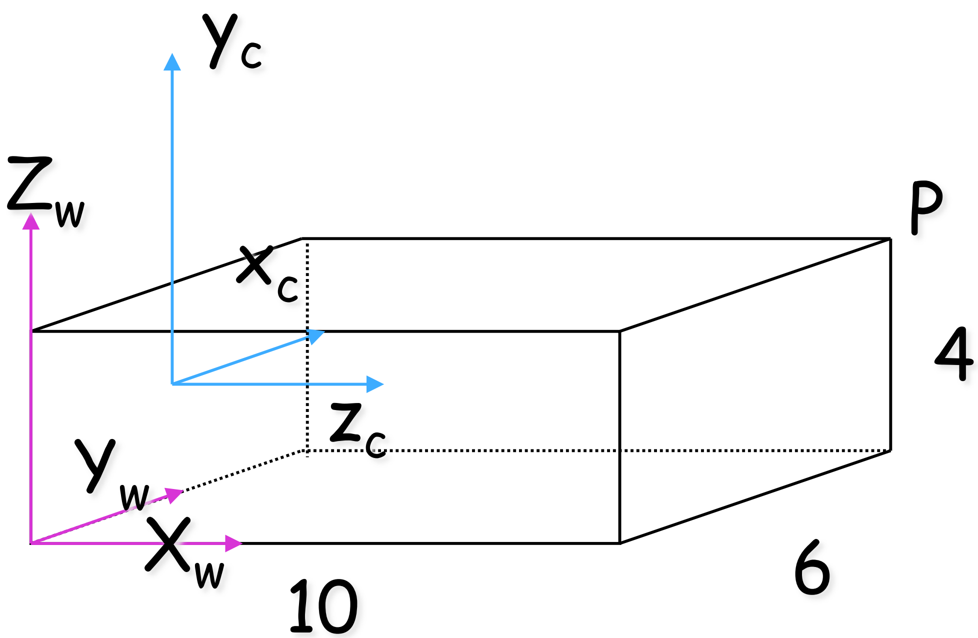
Example



$$P_w = \begin{bmatrix} 10 \\ 6 \\ 4 \\ 1 \end{bmatrix} \quad P_c = \begin{bmatrix} 3 \\ 2 \\ 10 \\ 1 \end{bmatrix}$$

$$P_c = M_{\text{ext}} . P_w$$

Example



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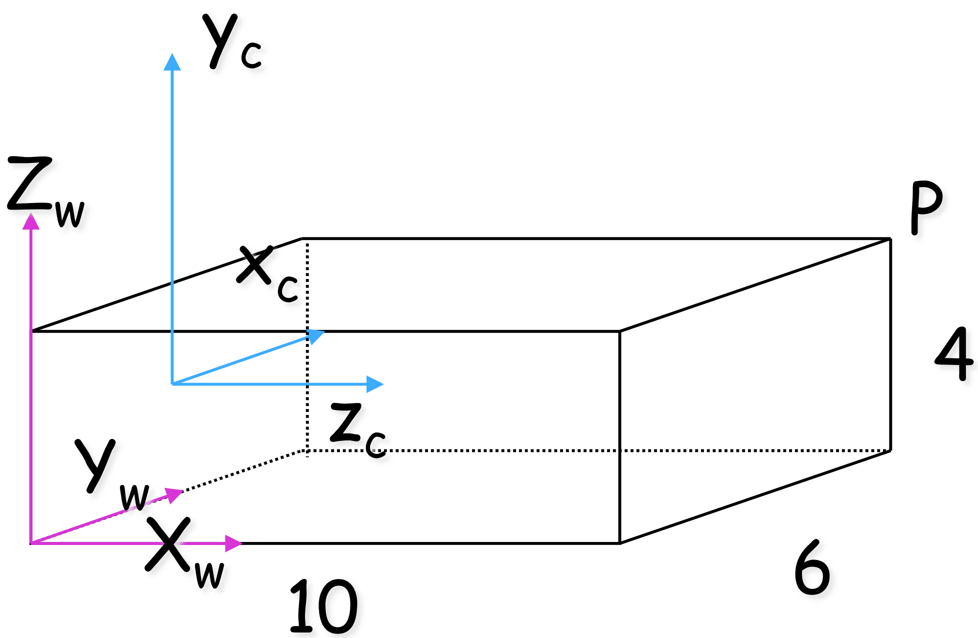
$$\begin{aligned} x_c &= y_w - 3 \\ y_c &= z_w - 2 \\ z_c &= x_w \end{aligned}$$

Example



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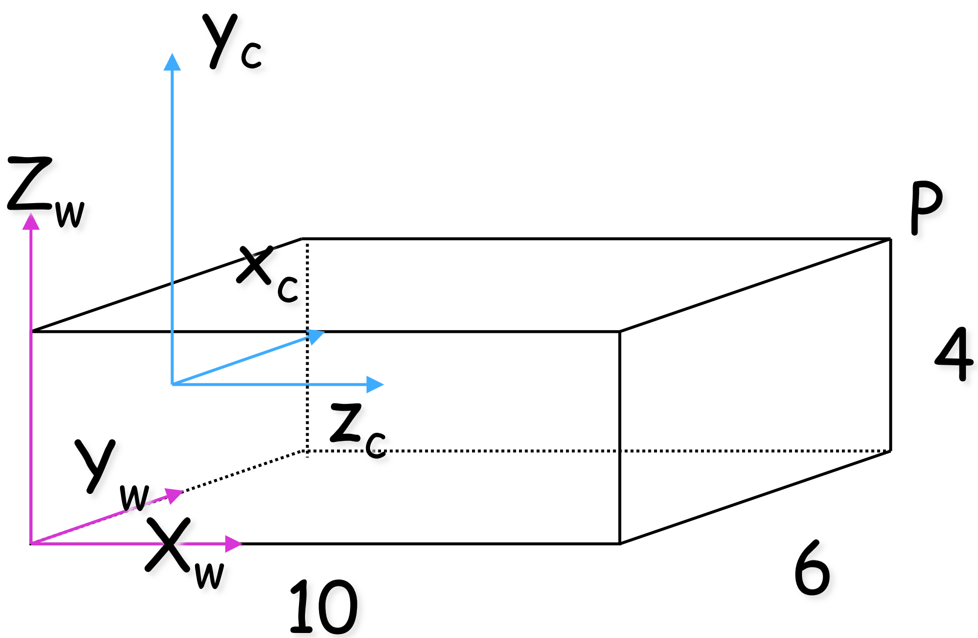
$$\begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & -3 \\ 0 & 0 & 1 & -2 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix}$$

Example



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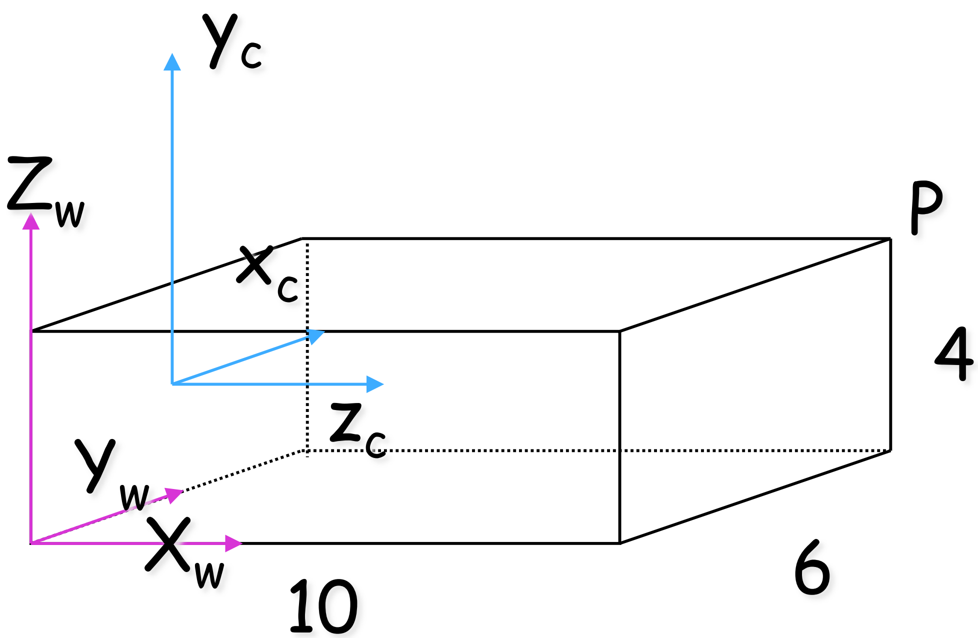
$$\begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} = \begin{array}{c} \begin{array}{cc} \quad \mathbf{R} \quad & \quad \mathbf{T} \end{array} \\ \begin{bmatrix} 0 & 1 & 0 & -3 \\ 0 & 0 & 1 & -2 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{array} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix}$$

Example



$$P_w = \begin{bmatrix} 10 \\ 6 \\ 4 \\ 1 \end{bmatrix} \quad P_c = \begin{bmatrix} 3 \\ 2 \\ 10 \\ 1 \end{bmatrix}$$

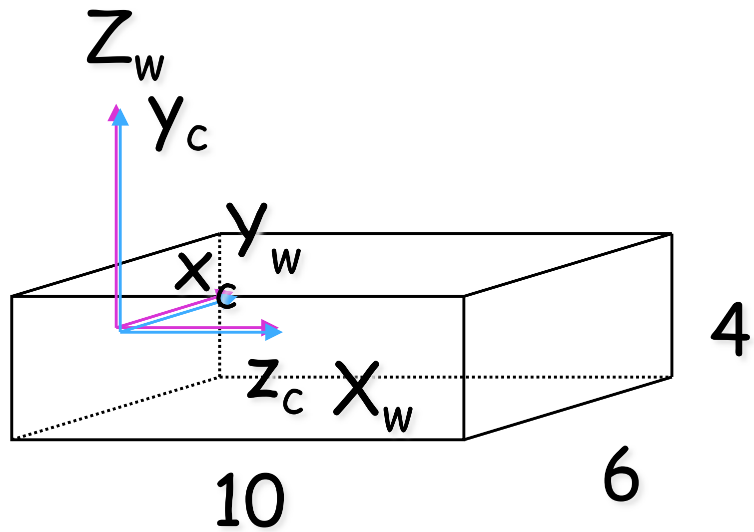
$$P_c = M_{\text{ext}} \cdot P_w$$

First, translate W to C

$t = (0, 3, 2)'$

Expressed in the ***current*** *coordinate system!*

Example



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$$P_c = M_{\text{ext}} \cdot P_w$$

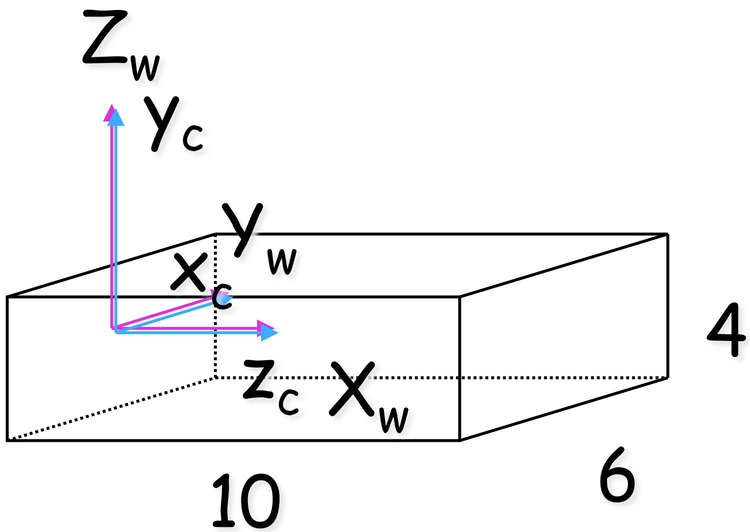
First, translate W to C

$$t = (0, 3, 2)'$$

Expressed in the ***current*** *coordinate system!*

$$\overset{\mathbf{T}}{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -3 \\ 0 & 0 & 1 & -2 \\ 0 & 0 & 0 & 1 \end{bmatrix}} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix}$$

Example

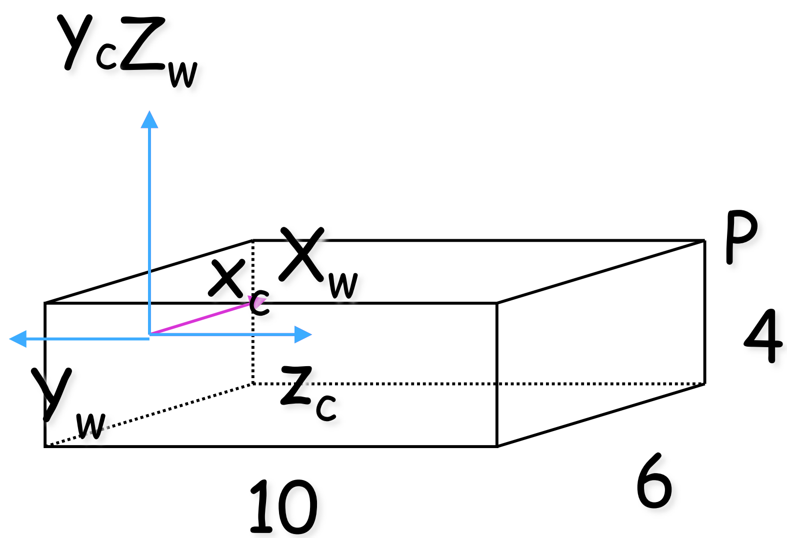


$$P_w = \begin{bmatrix} 10 \\ 6 \\ 4 \\ 1 \end{bmatrix} \quad P_c = \begin{bmatrix} 3 \\ 2 \\ 10 \\ 1 \end{bmatrix}$$

$$P_c = M_{\text{ext}} \cdot P_w$$

Next, rotate W' around Z_w, 90^o CCW (-90^o, CW)

Example



$$P_w = \begin{bmatrix} 10 \\ 6 \\ 4 \\ 1 \end{bmatrix} \quad P_c = \begin{bmatrix} 3 \\ 2 \\ 10 \\ 1 \end{bmatrix}$$

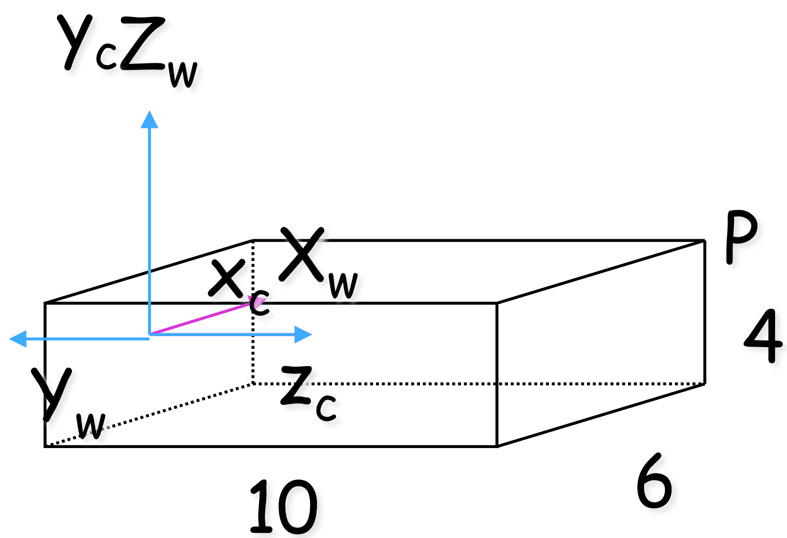
$$P_c = M_{\text{ext}} \cdot P_w$$

Next, rotate W' around Z_w, 90° CCW (-90°, CW)

$$R_z(\gamma) = \begin{bmatrix} \cos\gamma & -\sin\gamma & 0 \\ \sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\left[\underbrace{\begin{bmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{\mathbf{R_z}} \underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -3 \\ 0 & 0 & 1 & -2 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{\mathbf{T}} \right] \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix}$$

Example



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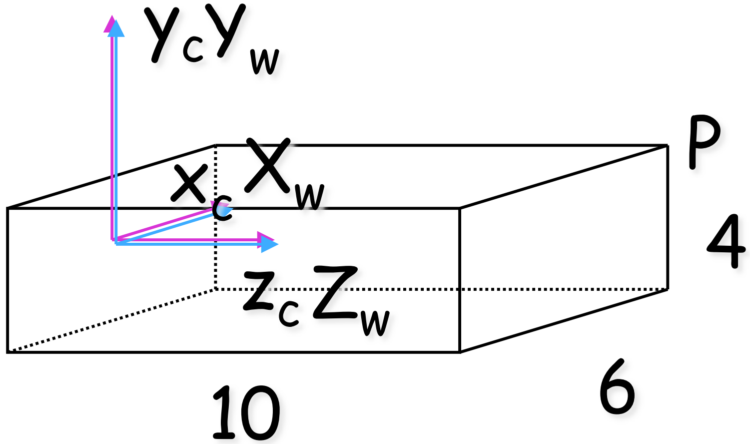
Example



$$P_w = \begin{bmatrix} 10 \\ 6 \\ 4 \\ 1 \end{bmatrix} \qquad P_c = \begin{bmatrix} 3 \\ 2 \\ 10 \\ 1 \end{bmatrix}$$

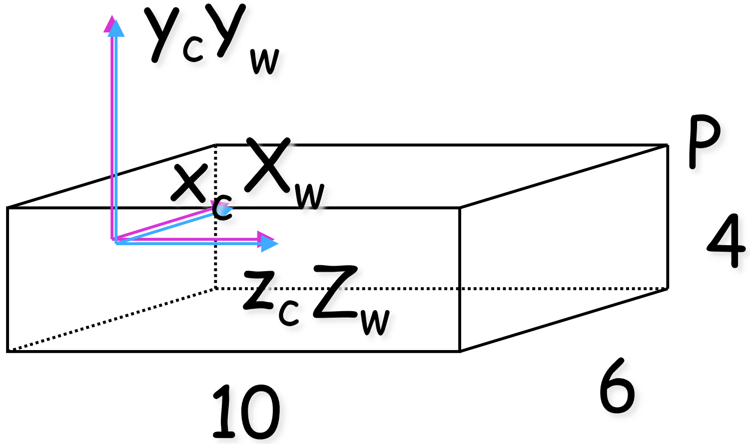
$$P_c = M_{\text{ext}} \cdot P_w$$

Next, rotate W'' around X_w, 90º CCW (-90º, CW)

$$R_x(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix}$$

$$\begin{array}{cccc} \mathbf{R_x} & \mathbf{R_z} & \mathbf{T} & \\ \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} & \begin{bmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} & \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -3 \\ 0 & 0 & 1 & -2 \\ 0 & 0 & 0 & 1 \end{bmatrix} & \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} \end{array}$$

Example

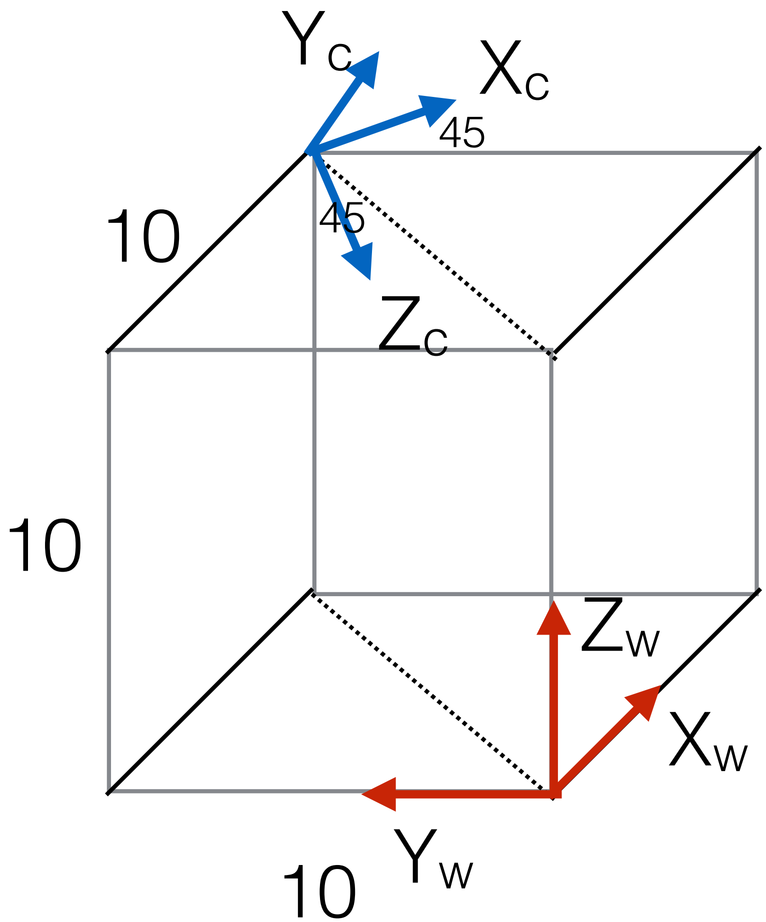


$$P_w = \begin{bmatrix} 10 \\ 6 \\ 4 \\ 1 \end{bmatrix} \quad P_c = \begin{bmatrix} 3 \\ 2 \\ 10 \\ 1 \end{bmatrix}$$

$$P_c = M_{\text{ext}} \cdot P_w$$

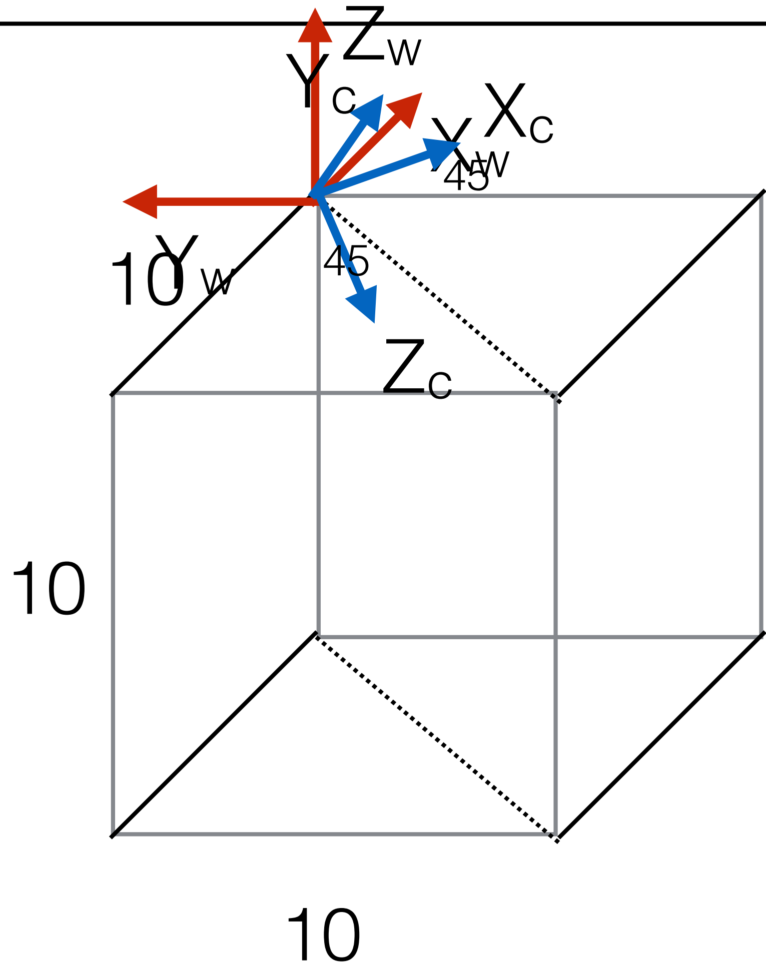
$$\begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} = \begin{array}{cc} \mathbf{R} & \mathbf{T} \\ \left[\begin{array}{ccc} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{array}\right. & \left.\begin{array}{c} -3 \\ -2 \\ 0 \\ 1 \end{array}\right] \end{array} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix}$$

Example



$$P_c = M_{\text{ext}} . P_w$$

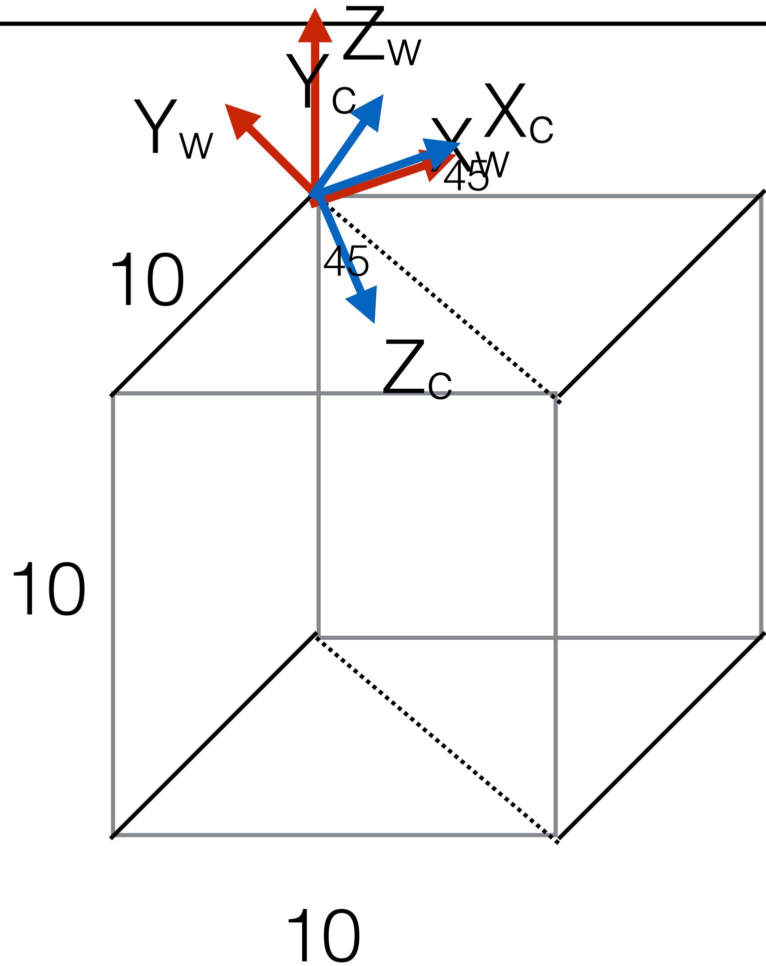
Example



$$P_c = M_{\text{ext}} . P_w$$

$$T = \begin{bmatrix} 1 & 0 & 0 & -10 \\ 0 & 1 & 0 & -10 \\ 0 & 0 & 1 & -10 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Example

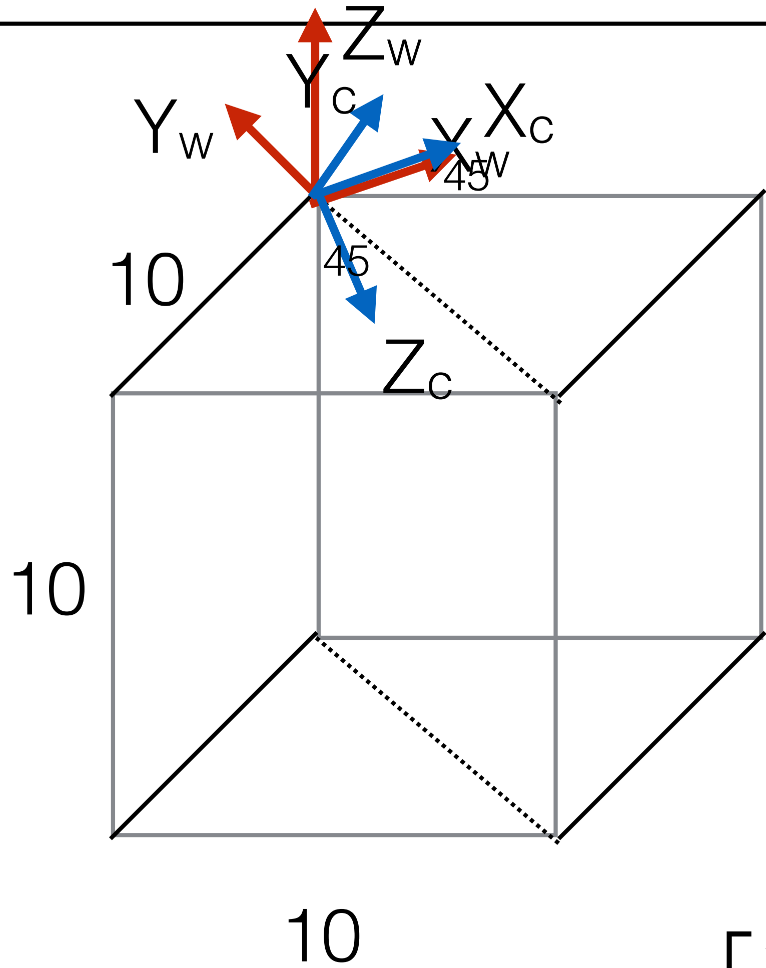


$$P_c = M_{\text{ext}} . P_w$$

$$T = \begin{bmatrix} 1 & 0 & 0 & -10 \\ 0 & 1 & 0 & -10 \\ 0 & 0 & 1 & -10 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_{Z,+45} = \begin{bmatrix} \cos 45 & -\sin 45 & 0 & 0 \\ \sin 45 & \cos 45 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} & 0 & 0 \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

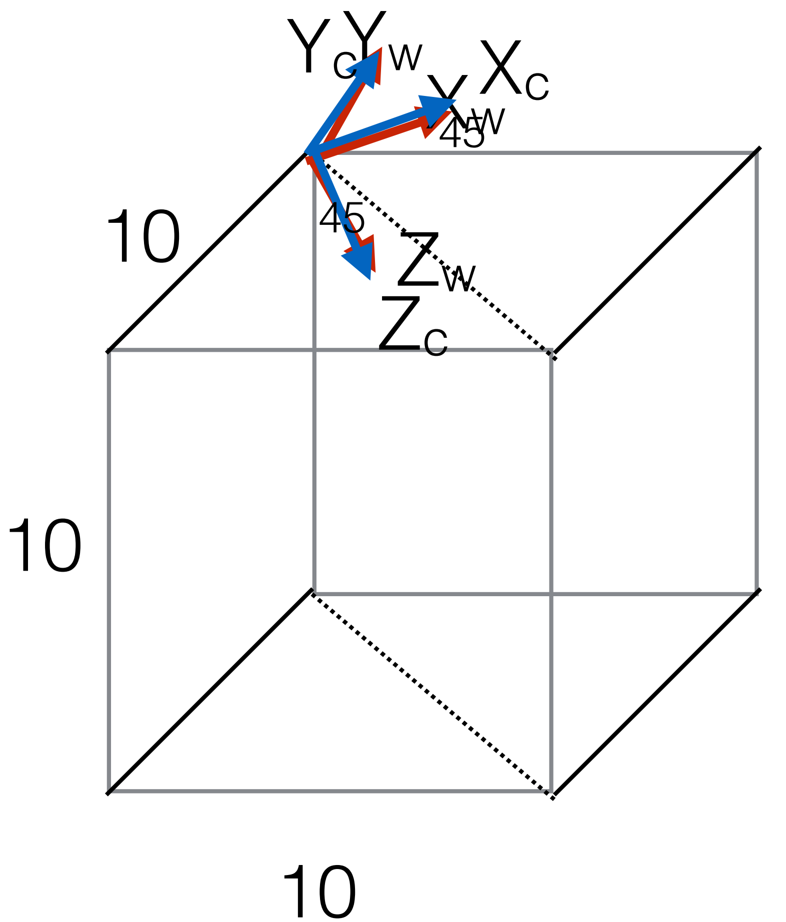
Example



$$P_c = M_{\text{ext}} . P_w$$

$$R_{Z,+45} . T = \begin{bmatrix} \frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} & 0 & 0 \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & 0 & -10\sqrt{2} \\ 0 & 0 & 1 & -10 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

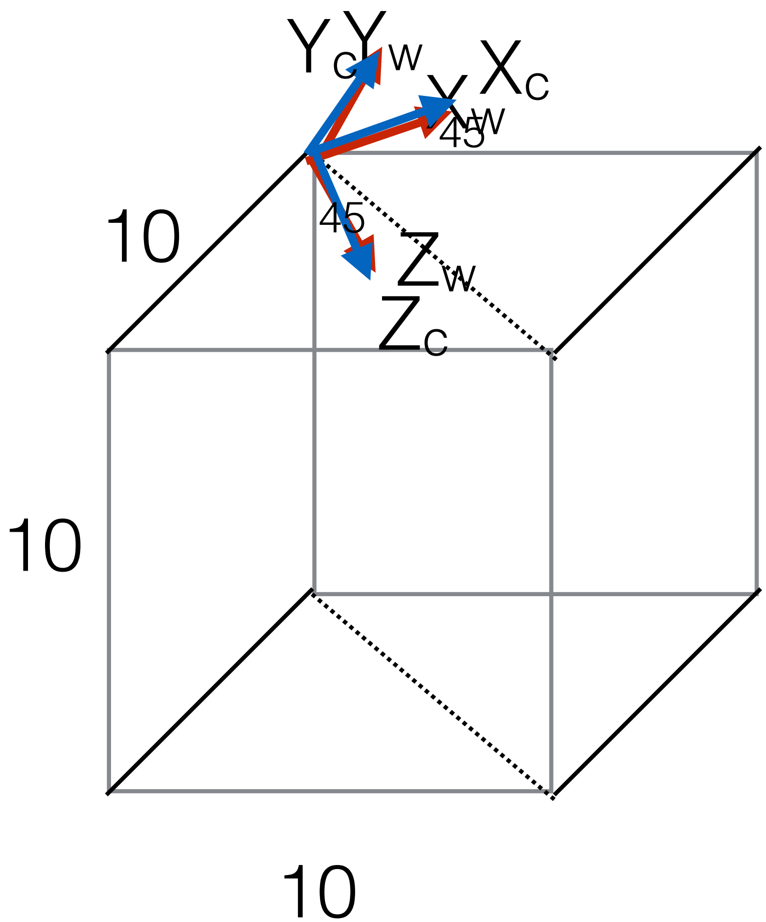
Example



$$P_c = M_{\text{ext}} . P_w$$

$$R_{X,-135} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos -135 & -\sin -135 & 0 \\ 0 & \sin -135 & \cos -135 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -\frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & 0 \\ 0 & -\frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

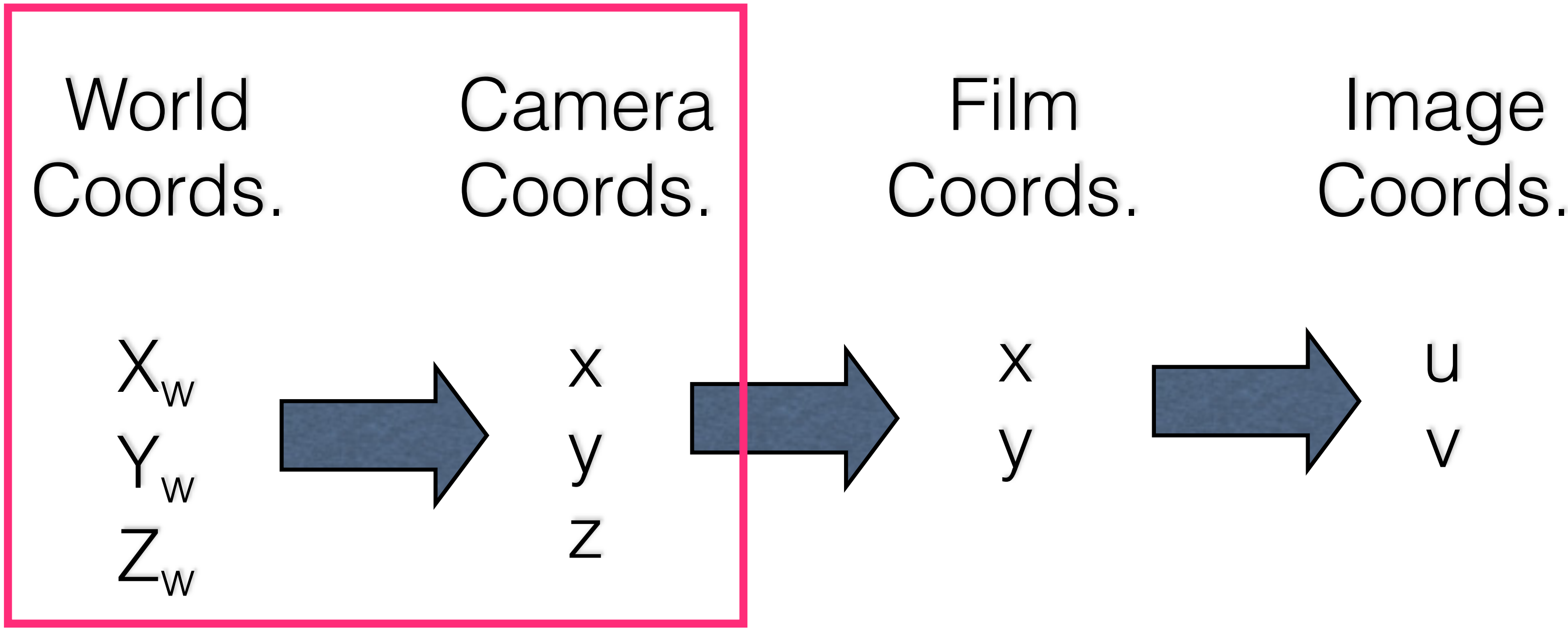
Example



$$P_c = M_{\text{ext}} . P_w$$

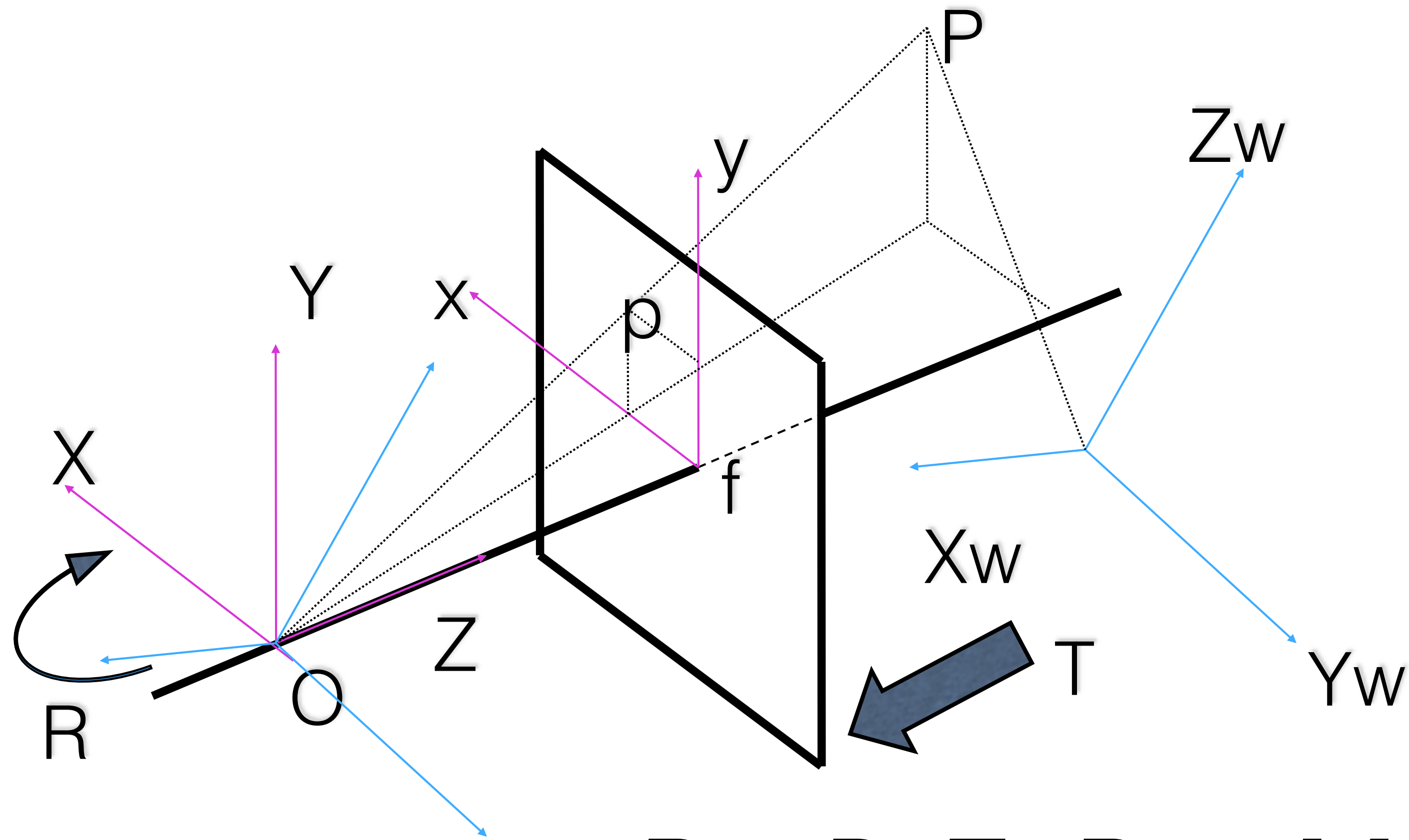
$$M = R_{X,-135} . R_{Z,+45} . T = \begin{bmatrix} \frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} & 0 & 0 \\ -1/2 & -1/2 & \frac{\sqrt{2}}{2} & 10 - 5\sqrt{2} \\ -1/2 & -1/2 & -\frac{\sqrt{2}}{2} & 10 + 5\sqrt{2} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Coordinate Systems



Rigid transformation: rotation & translation

Pinhole Camera Model
(World Coordinates)



$$P = R \times T \times P_w = M_{ext} \times P_w$$

$$p = M_{int} P = M_{int} M_{ext} \times P_w$$

Putting it all together:

- Extrinsic parameters (R, T):

$$P = R \times T \times P_w = M_{ext} \times P_w$$

- Intrinsic parameter (f):

$$p = M_{int} P = M_{int} M_{ext} \times P_w$$

$$p = M \times P_w$$

M is 3x4
M has 6 dof
(assuming f is known)

How do we find M?

Each image point (x, y) must satisfy:

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{31} & m_{33} & m_{34} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$$x = x'/z' \qquad y = y'/z'$$

$$xz' = m_{11}X + m_{12}Y + m_{13}Z + m_{14}$$
$$yz' = m_{21}X + m_{22}Y + m_{23}Z + m_{24}$$
$$z' = m_{31}X + m_{32}Y + m_{33}Z + m_{34}$$

$$0 = m_{11}X + m_{12}Y + m_{13}Z + m_{14} - m_{31}Xx - m_{32}Yx - m_{33}Zx - m_{34}x$$
$$0 = m_{21}X + m_{22}Y + m_{23}Z + m_{24} - m_{31}Xy - m_{32}Yy - m_{33}Zy - m_{34}y$$

Finding M:

M has 12 entries, but only 6 dof.

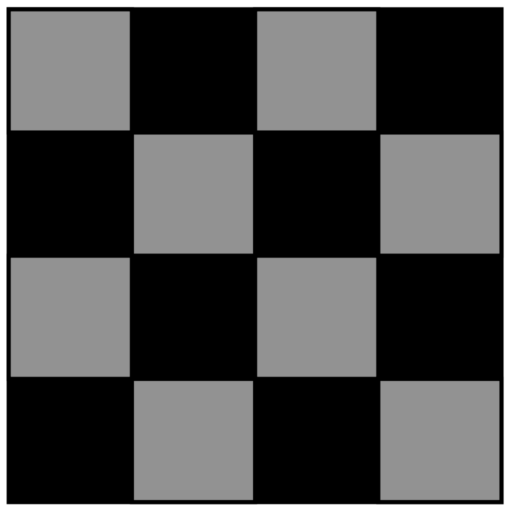
Each image point provides 2 equations.

Solve a system of linear equations.

$$0 = m_{11}X + m_{12}Y + m_{13}Z + m_{14} - m_{31}Xx - m_{32}Yx - m_{33}Zx - m_{34}x$$
$$0 = m_{21}X + m_{22}Y + m_{23}Z + m_{24} - m_{31}Xy - m_{32}Yy - m_{33}Zy - m_{34}y$$

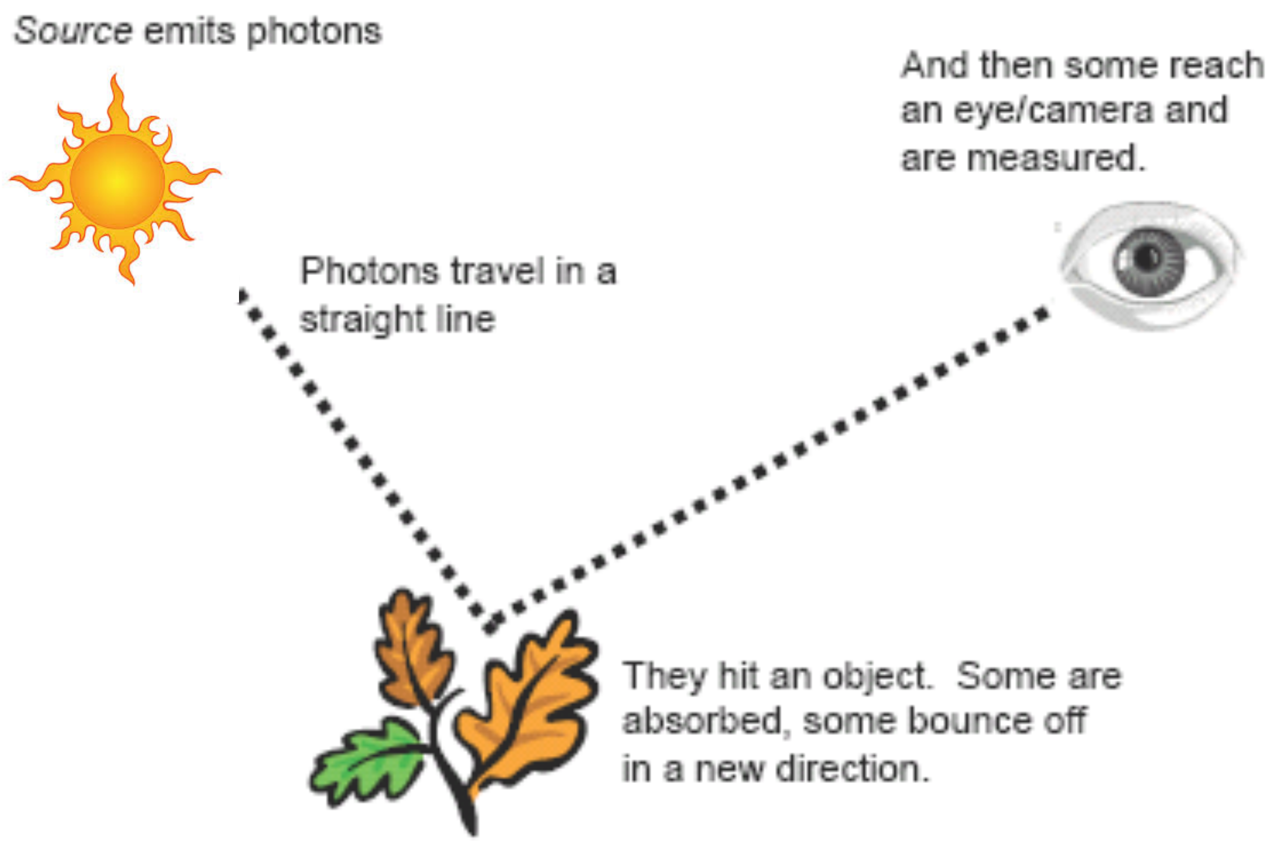
How do we find point correspondences?

Use special calibrating pattern:

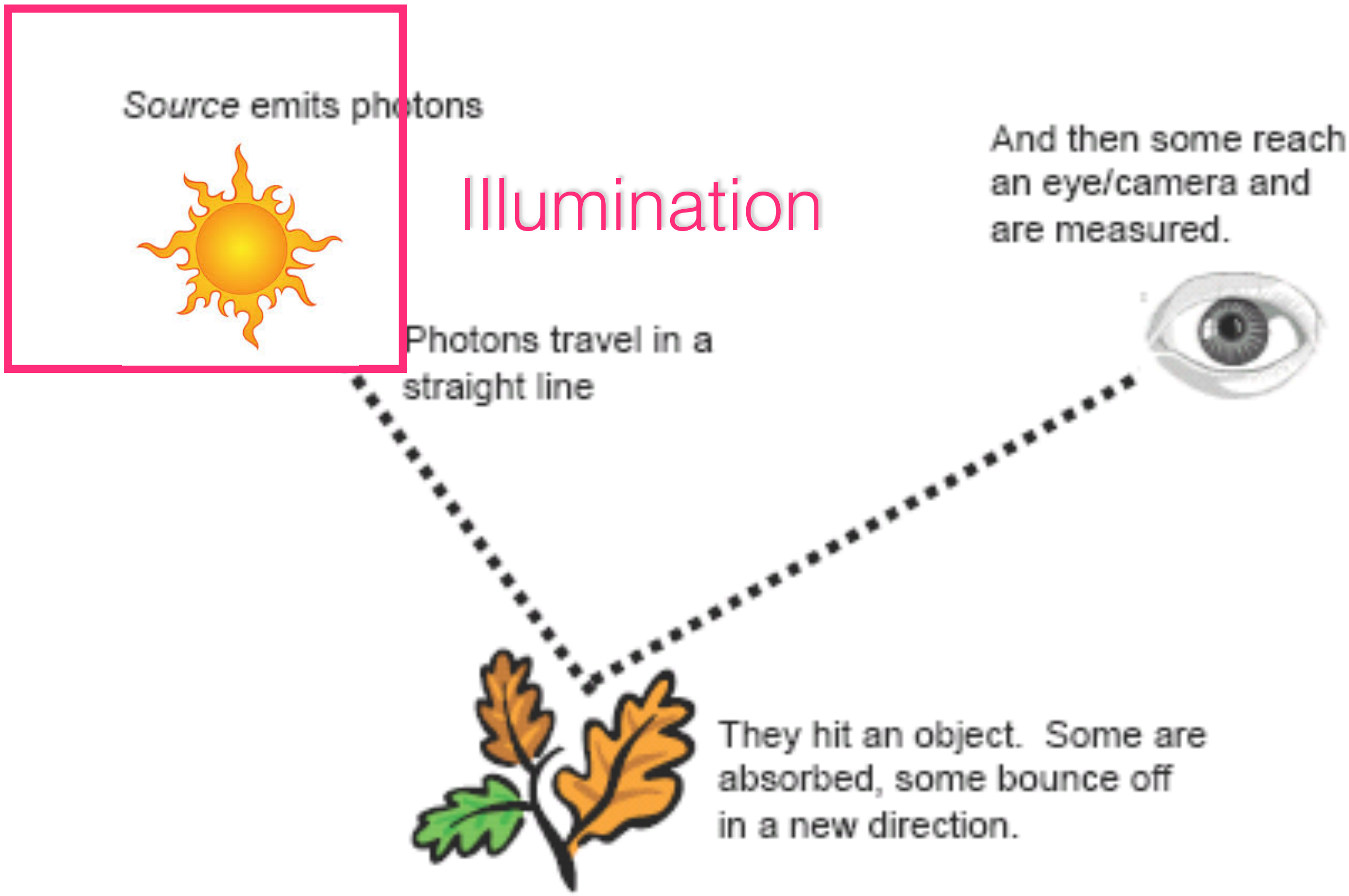


Corners are “easy” to detect and “identify”.

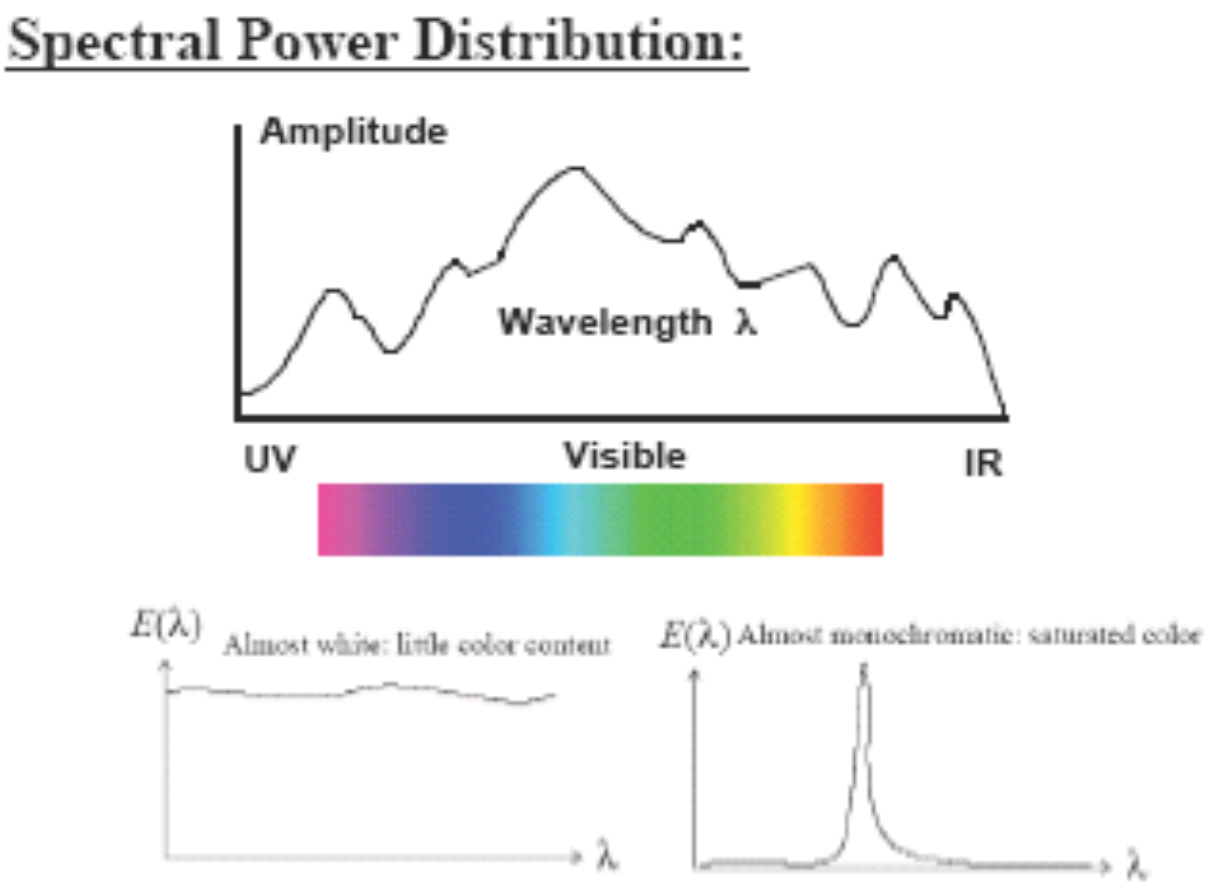
Photometry Overview



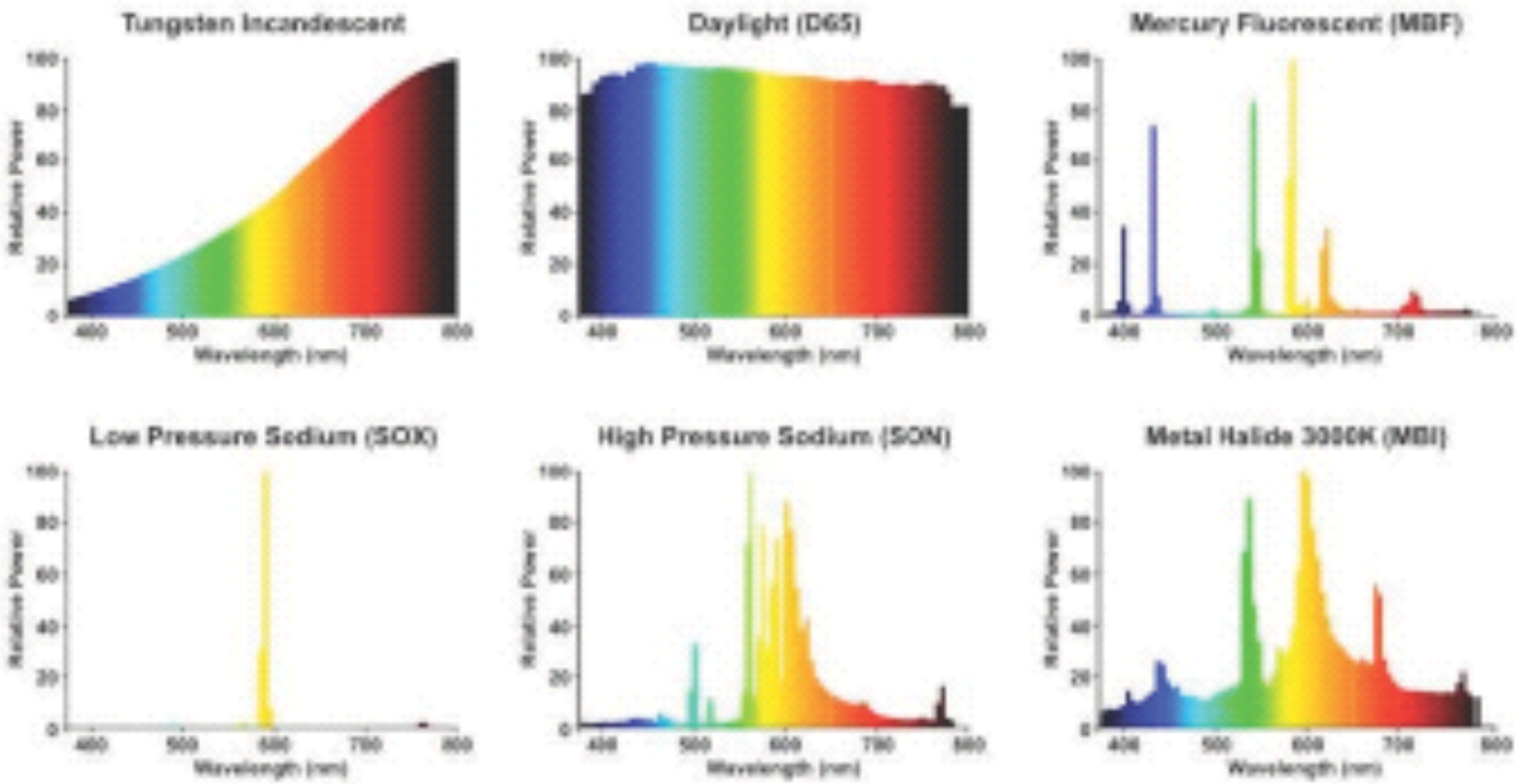
Light Transport



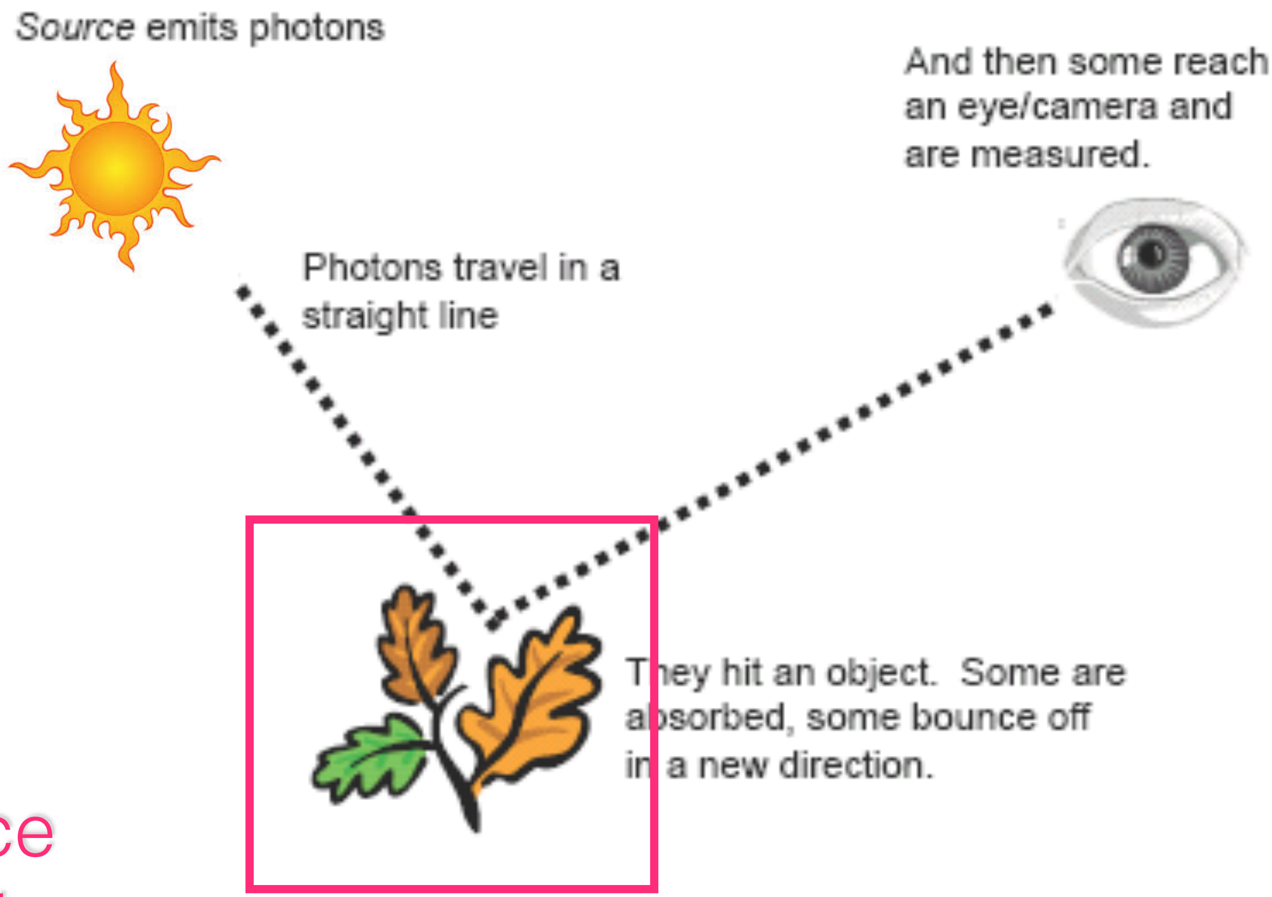
Color of Light Source



Some Light Source SPDs

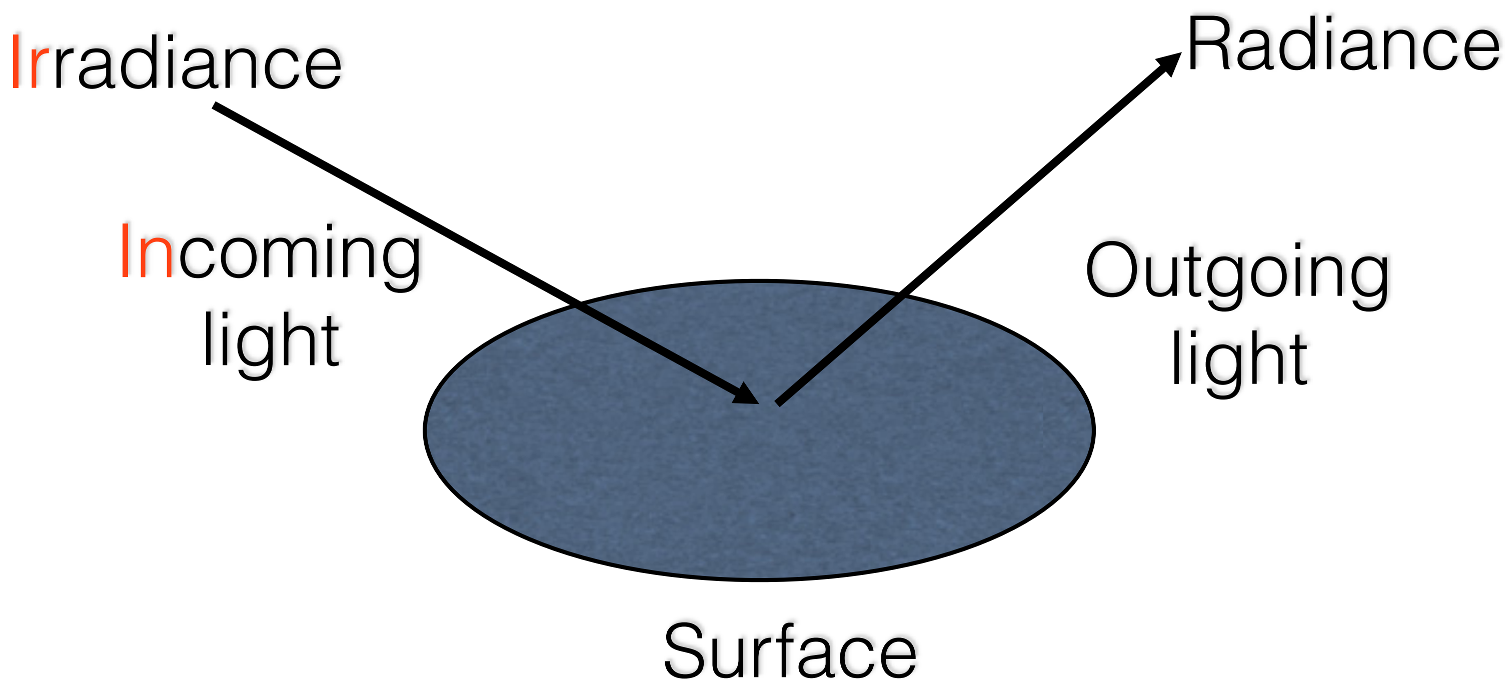


Light Transport



Surface Reflection

(Ir)radiance

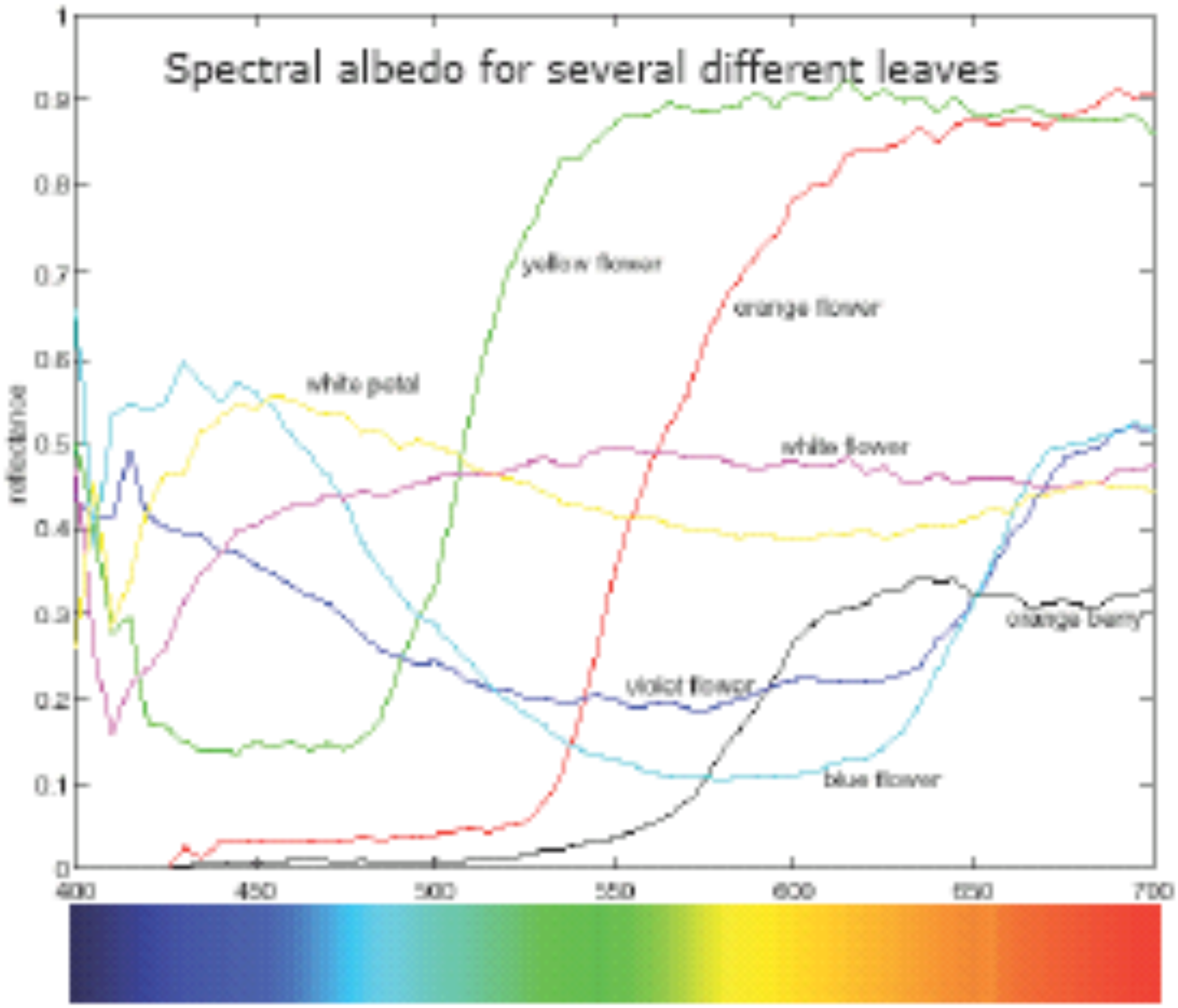


$$f_r(\theta_i, \phi_i, \theta_r, \phi_r; \lambda)$$

BRDF: bidirectional reflectance distribution function

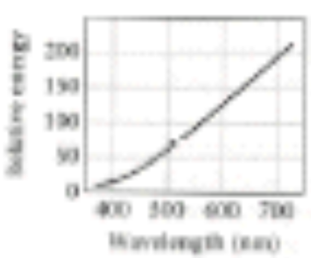
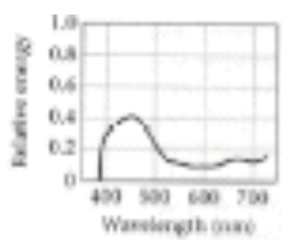
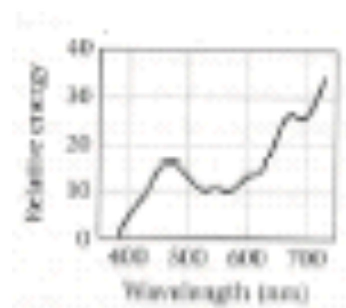
Spectral Albedo

Ratio of incoming to outgoing radiation at different wavelengths.



Spectral Radiance

Often are more interested in relative spectral composition than in overall intensity, so the spectral BRDF computation simplifies to a wavelength-by-wavelength multiplication of relative energies

Spectral Irradiance		Spectral Albedo		Spectral Radiance
	*		=	

Light Transport

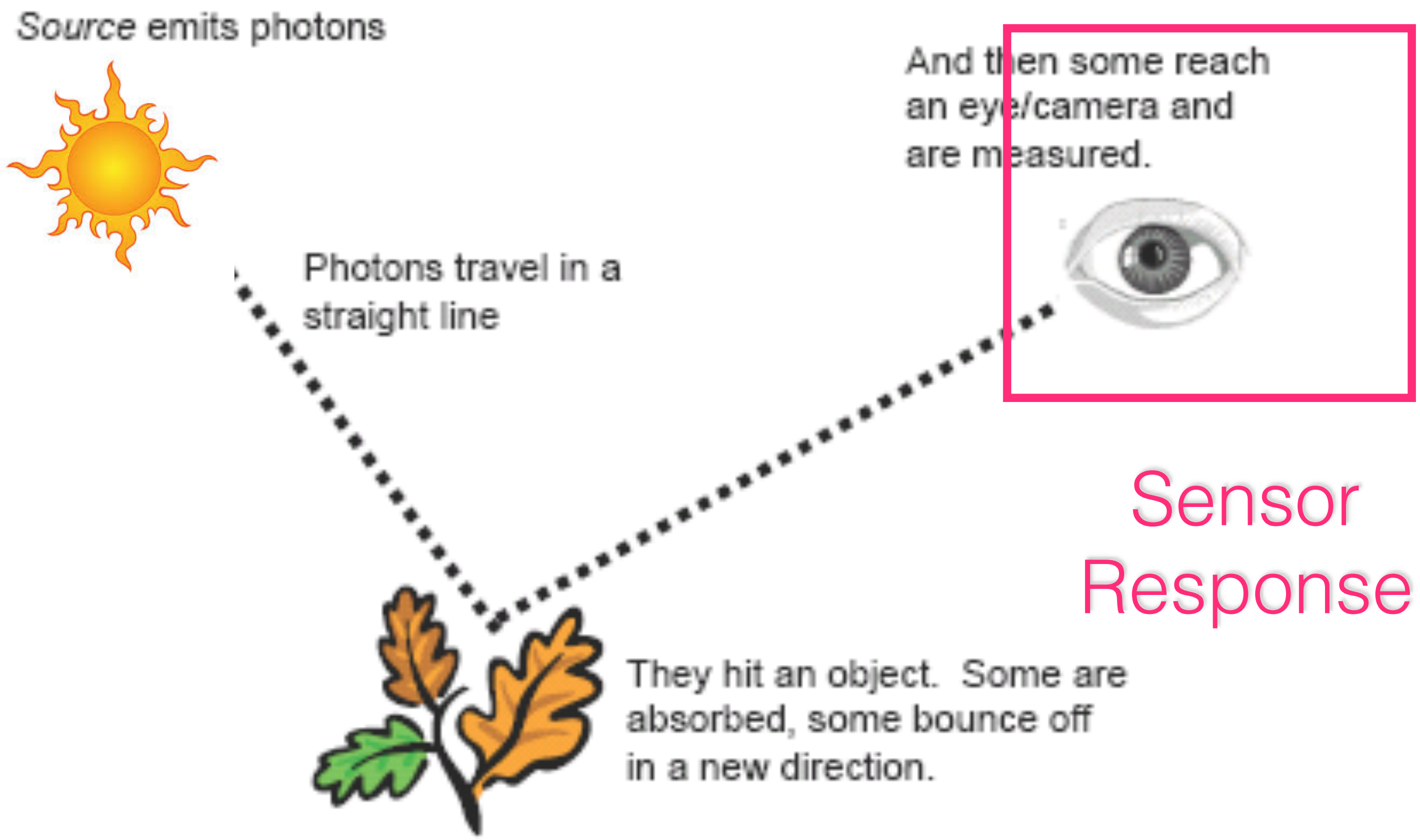
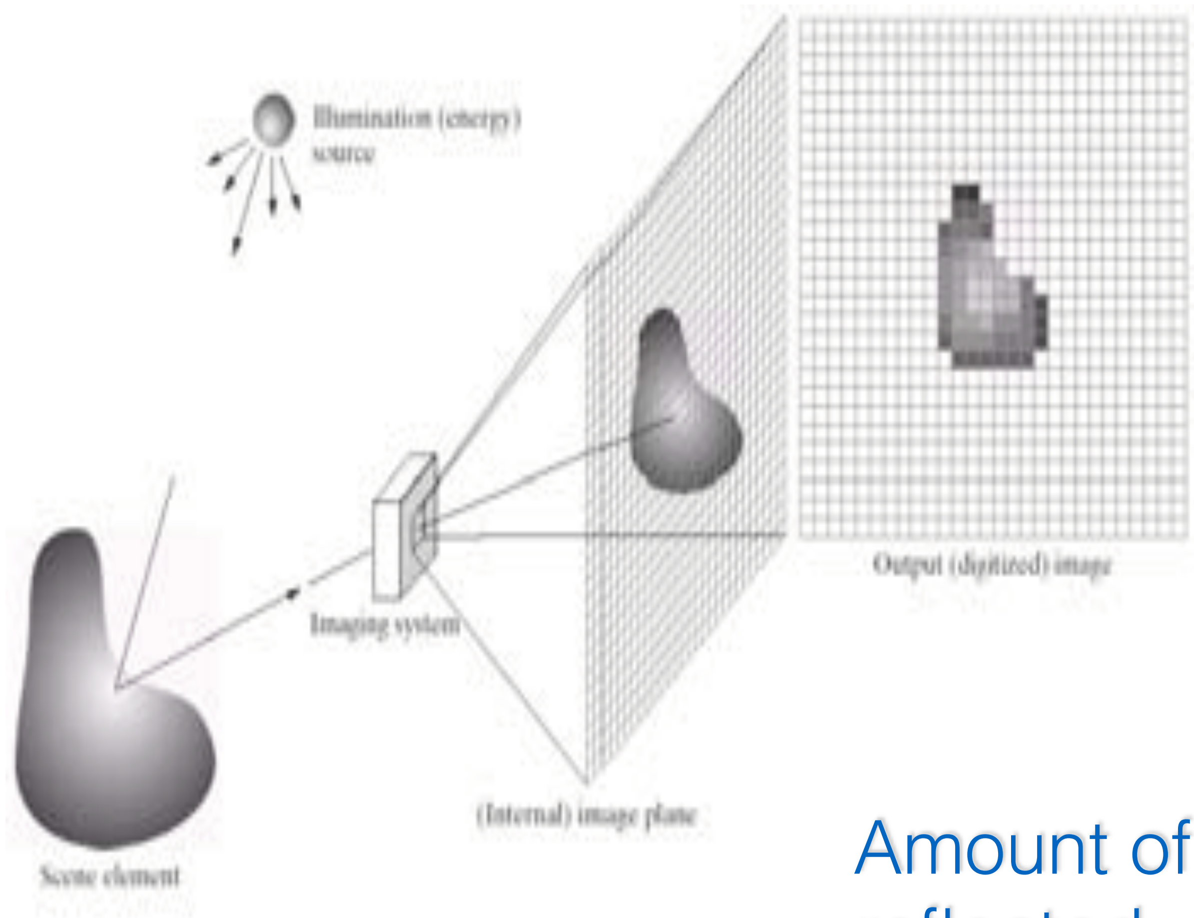


Image Formation Model



Amount of illumination reflected

$$f(x,y) = i(x,y)r(x,y)$$

Gray level

illumination

Color Image Processing
(Digital Image Processing, Gonzalez & Woods)

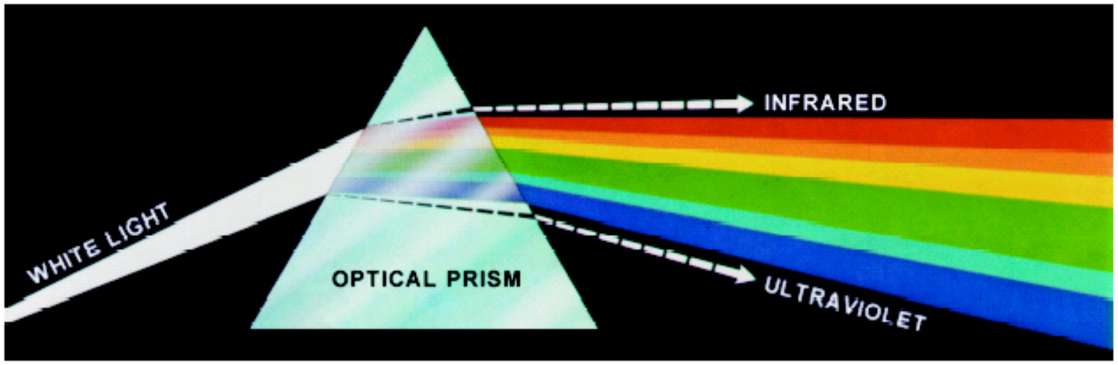


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

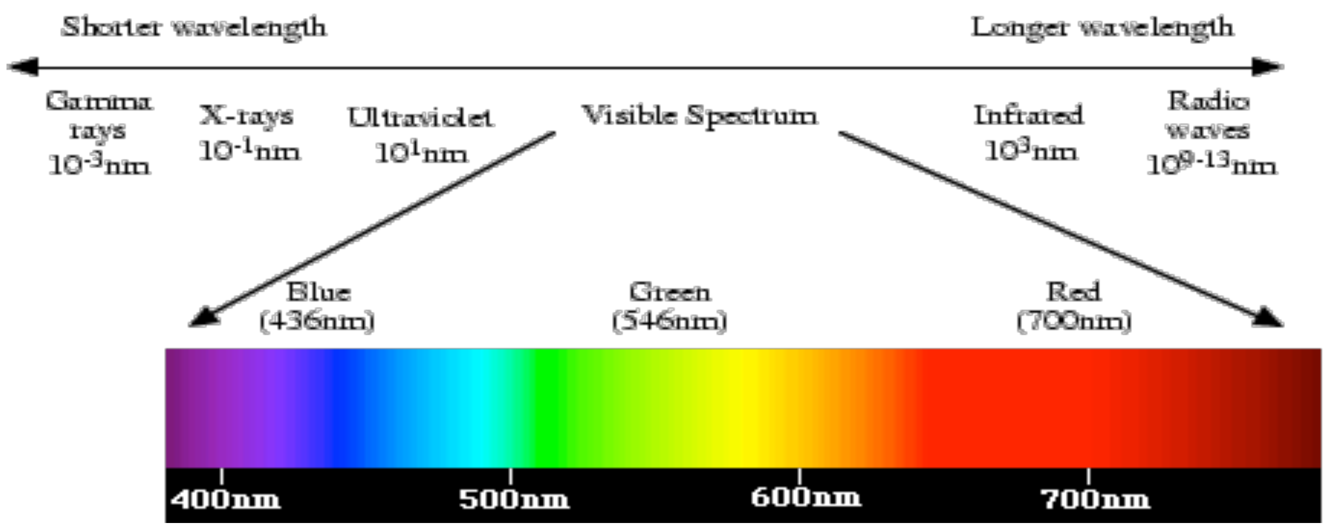
Color Image Processing

- Use of color in image processing:
  - Color is a powerful descriptor:
    - Using color simplifies tasks such as object recognition
  - Humans can distinguish better colors than gray levels:
    - Makes images more attractive to humans
- Color image processing:
  - **Full color**: images are acquired with a full color sensor (color camera, color scanner)
  - **Pseudo-color**: a color is assigned to a range of gray level values

Color Fundamentals: Light and Color

Light is electromagnetic radiation

Visible light: 400-700nm. range



Color Fundamentals

Perceived color of an object is determined by the light it reflects.

If an object reflects:

- balanced light on all frequencies of the visible spectrum it appears white.
- in a limited band it appears as colored.

Achromatic light:

- Void of color
- Its only attribute is intensity (amount).

Chromatic Light

Visible spectrum is 400 - 700 nm

It is characterized by:

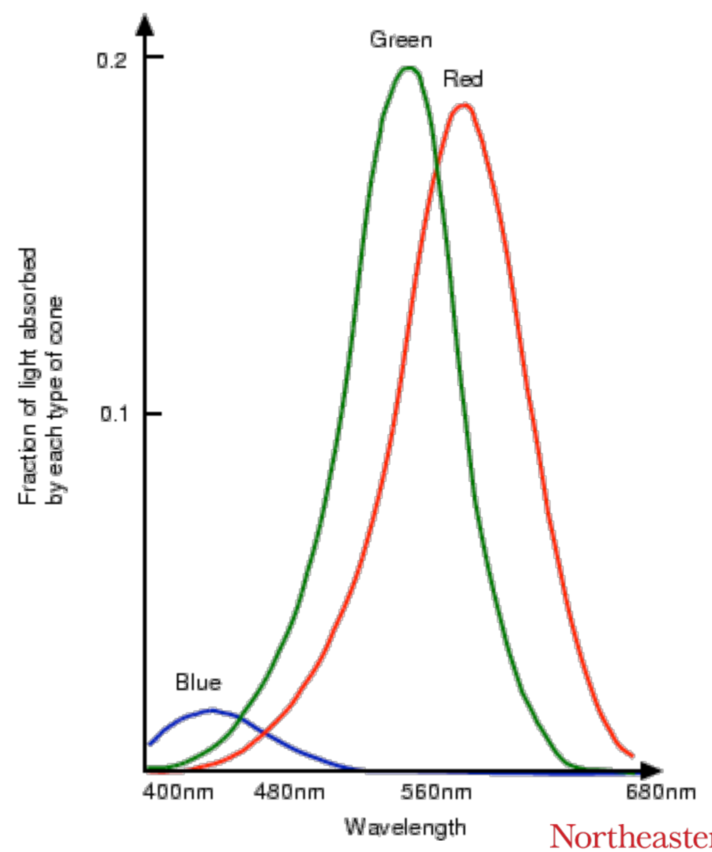
1. **Radiance**: total amount of energy that flows form the light source. (Measured in watts)
2. **Luminance**: The amount of energy an observer perceives from a light source. (Measured in lumens)
3. **Brightness**: A subjective descriptor of intensity, impossible to measure, embodies the achromatic notion of intensity.

Color and the Human Eye

6 to 7 Million cones in the human eye

- 65% (red)
- 33% (green)
- 2% (blue)

Cones are sensitive to colored light, but not very sensitive to dim light.

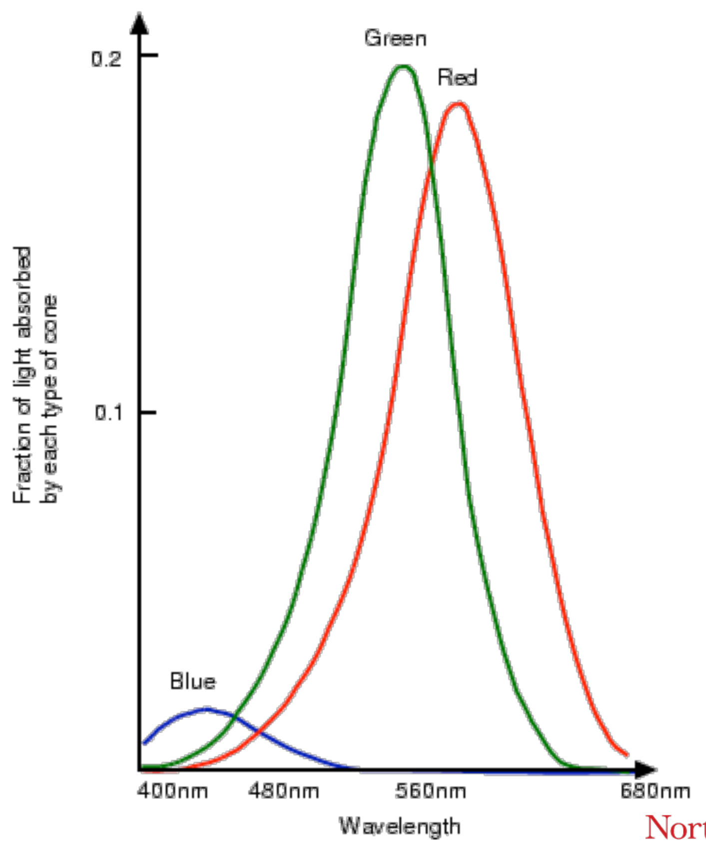


Color and the Human Eye

Primary colors of light:

- RED (R)
- GREEN (G)
- BLUE (B)

CIE (Commission Internationale de l'Eclairage: International Commission on Illumination) defined:



RED = 700nm

GREEN = 546.1nm

BLUE = 435.8nm

The 3 primaries are **not** capable of producing all visible colors.

Secondary Colors of Light

Are produced by adding primary colors

- Magenta = red + blue
- Cyan = green + blue
- Yellow = red + green

Color TV is an example of additive light colors

- Color tubes have three electron-sensitive phosphor (one for each primary)
- The perceived color is the addition of the triad

Primary Colors of Pigments

Are the ones that subtract (absorb) a primary color of light and reflect the other two.

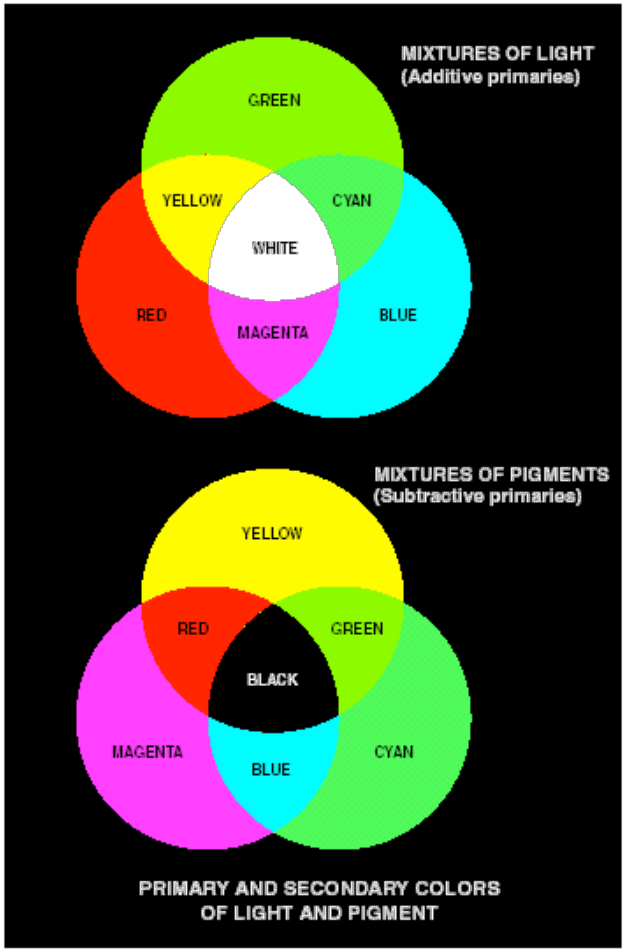
Primary color of pigments are:

- Magenta (M)
- Cyan (C)
- Yellow (Y)

Printers use a “subtracting” color model

- Three color cartridges: M,C,Y
- Black can be made by combining all 3 primary colors
- Less expensive to have a separate black cartridge

Secondary Colors



a
b

FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

Light

Magenta = red + blue

Cyan = green + blue

Yellow = red + green

Pigments

Magenta = white - green

Cyan = white - red

Yellow = white - blue

Color Characteristics

Brightness:

- Achromatic notion of intensity
- Actual amount of light

Hue:

- Dominant wavelength
- Represents the dominant perceived color

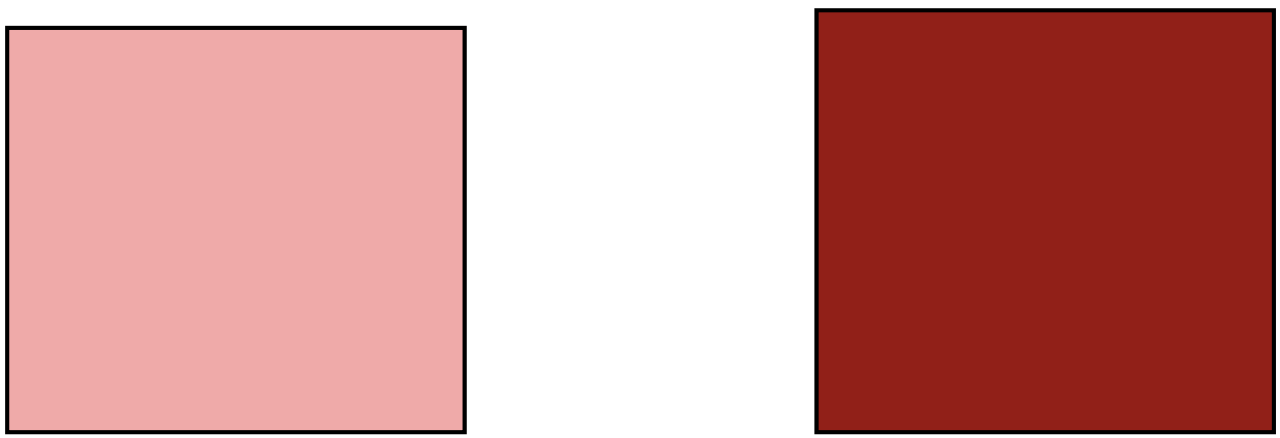
Saturation:

- Excitation purity
- Amount of white light mixed with the color

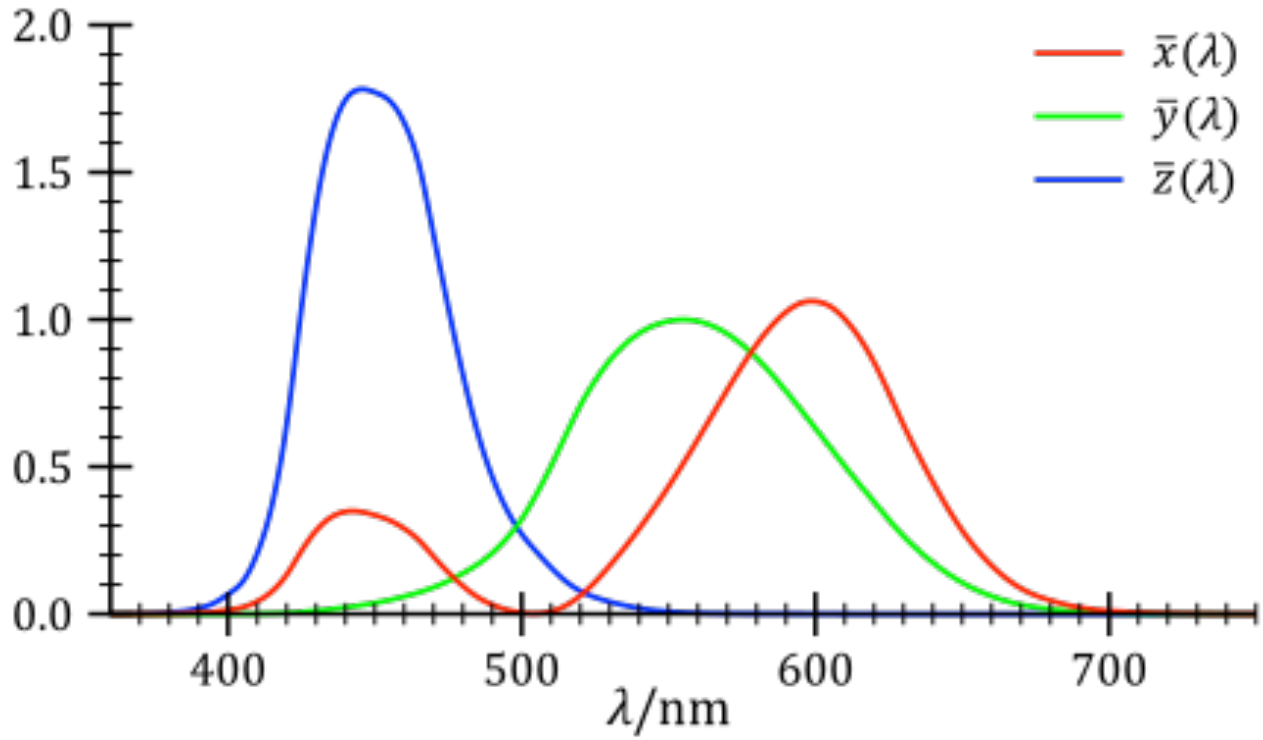
Hue and saturation together are called chromaticity

Chromaticity

These boxes have the same hue and intensity



CIE standard observer color matching function



$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Tristimulus

The amount of R,G,B needed to form a color

Denoted by X,Y,Z

A color can be specified by its 3 coefficients:

$$x = \frac{X}{X+Y+Z}$$

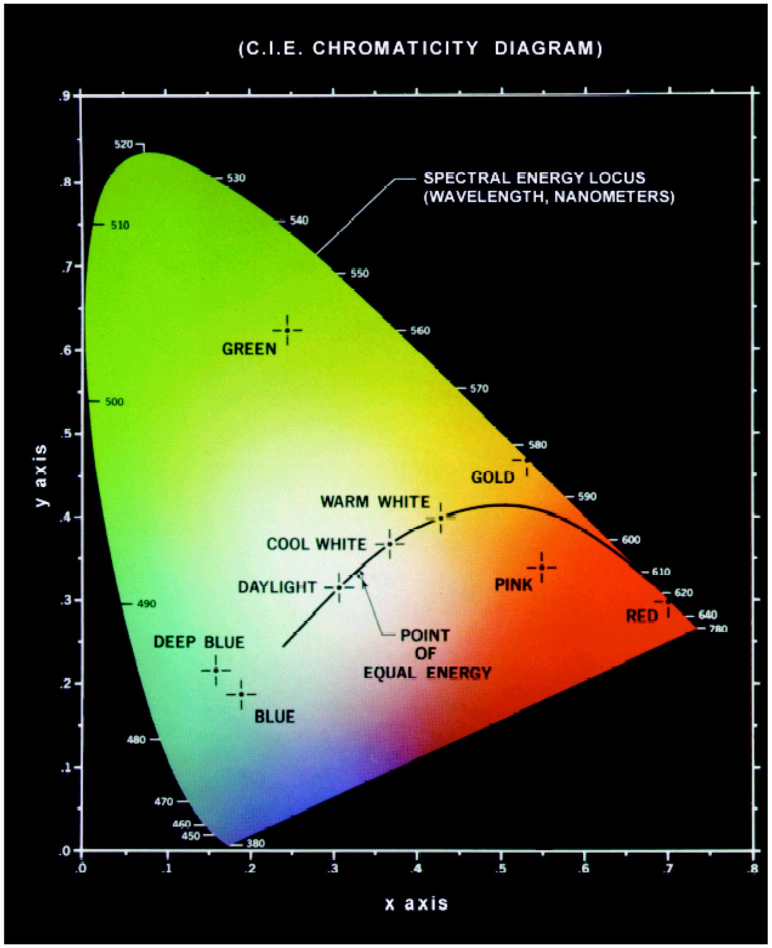
$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

CIE Chromaticity Diagram

FIGURE 6.5
Chromaticity diagram.
(Courtesy of the General Electric Co., Lamp Business Division.)



Each color is represented as a point in a 2D diagram (x,y).
$z = 1 - (x+y)$

Any point on the boundary is fully saturated (saturation =1).

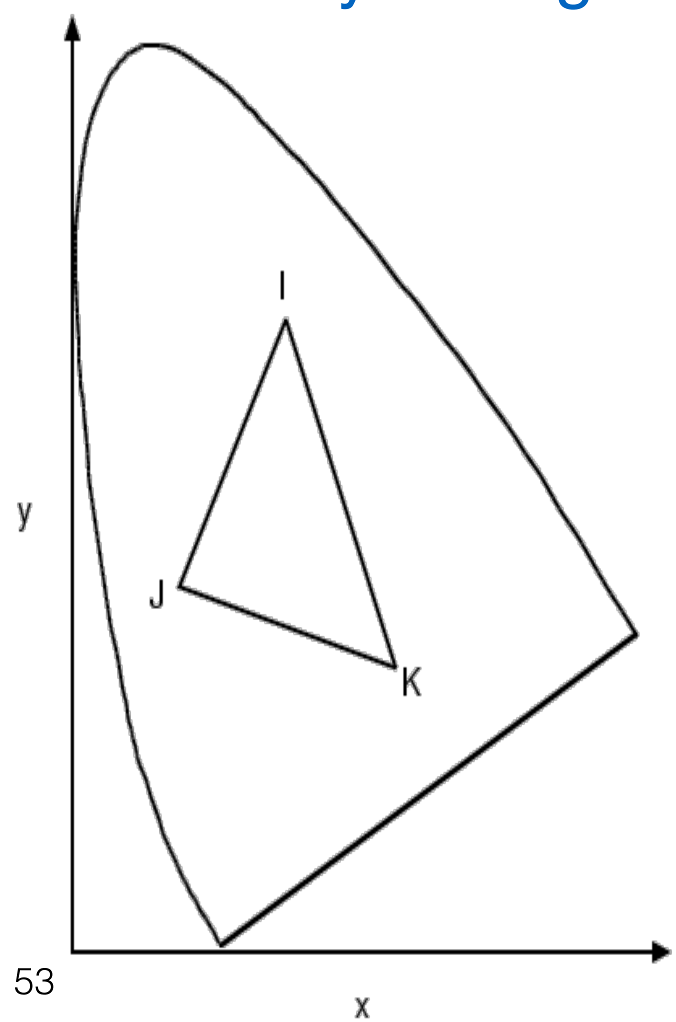
White: point of equal energy $x=y=z=1/3$ (saturation = 0)

As a point moves to the interior, its saturation decreases.

Mixing Colors on CIE diagram

Any color along a line can be obtained by mixing the colors of the endpoints.

Any point in a triangle can be obtained by mixing the colors of the vertices.



Color Gamut

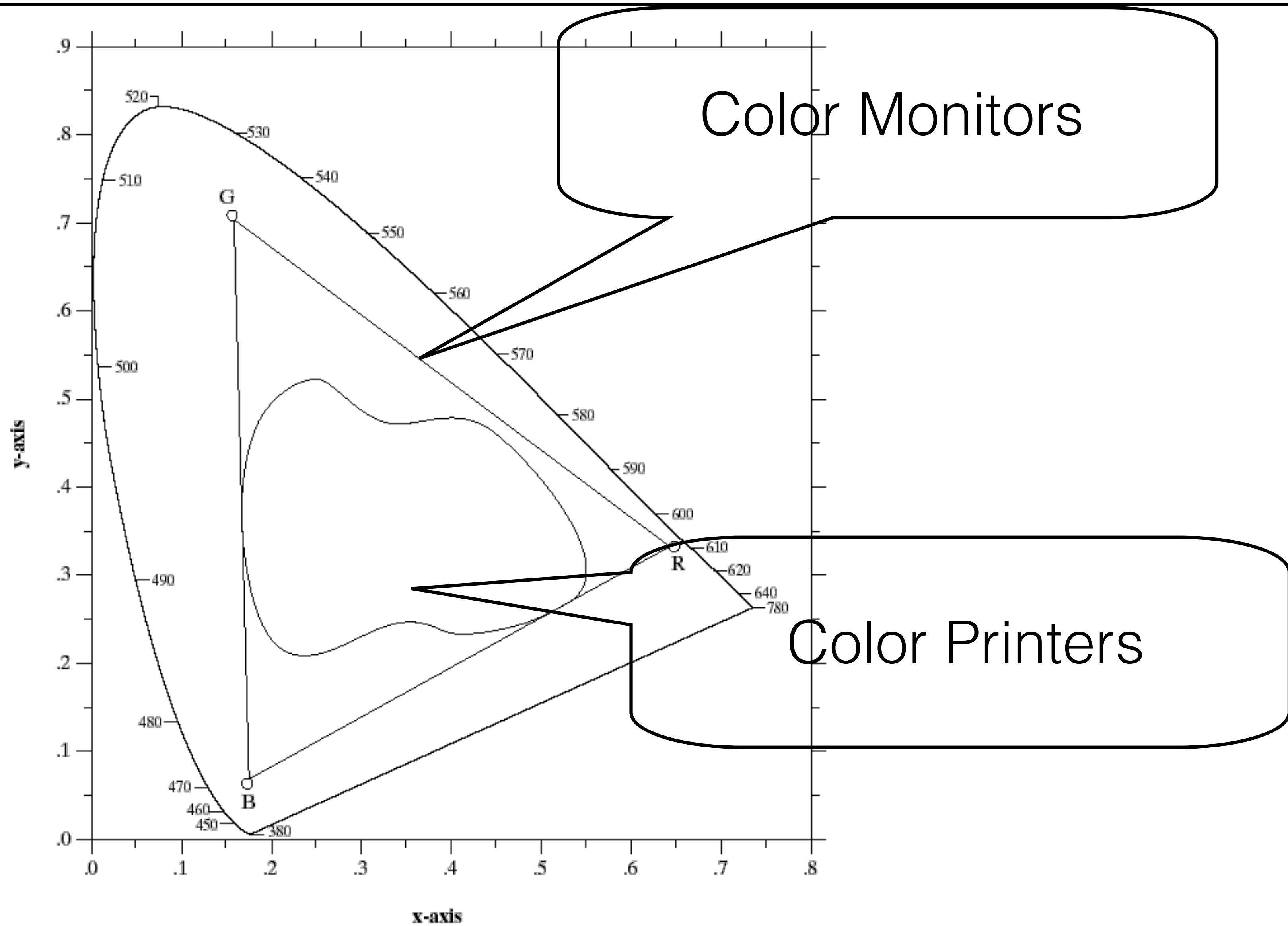


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

COLOR MODELS

Color Models

They provide a standard way of specifying a particular color using a 3D coordinate system.

- Hardware oriented:
  - RGB (monitors, cameras)
  - CMY (printers)
  - YIQ (luminance, inphase, quadrature) (tv)
- Image processing oriented:
  - HIS (hue, intensity, saturation)
    - Decouples color from intensity
    - The way humans describe and interpret color

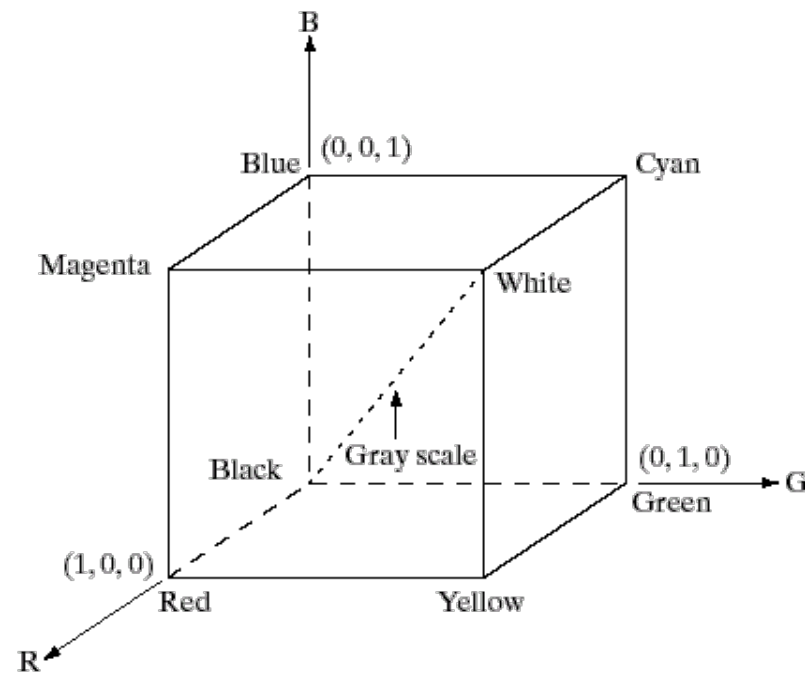
The RGB Color Model

Each color appears in its primary spectral components of R,G,B

It is based on a Cartesian coordinate system

Color values are normalized in the [0,1] range

Gray scale values are points with R=G=B (diagonal)



RGB Model

The number of bits used to represent a pixel is called "depth"

3 bands, 8-bit/band = 24 bits depth

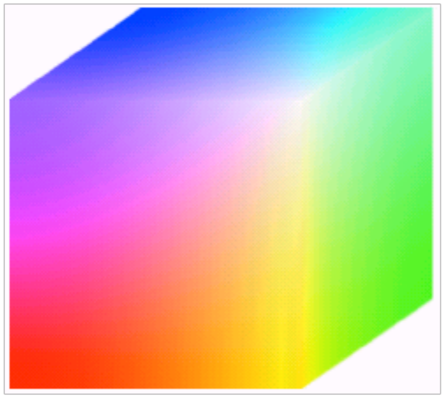


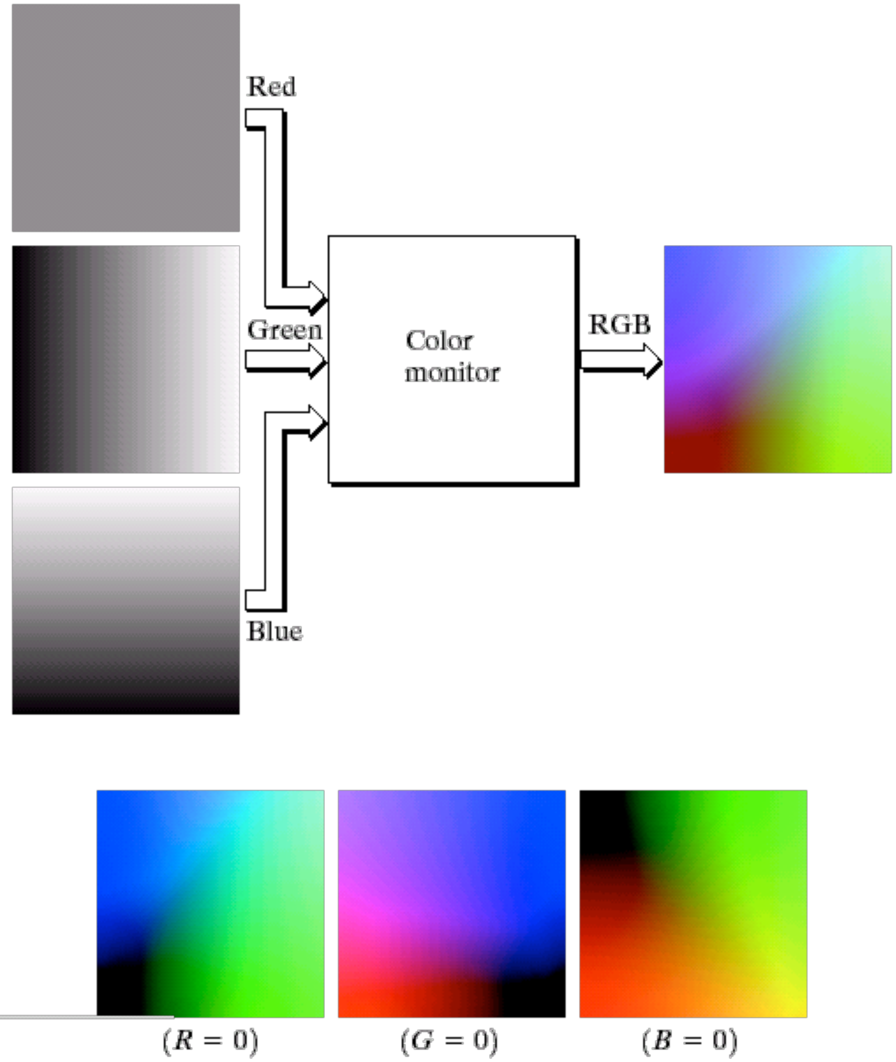
FIGURE 6.8 RGB 24-bit color cube.

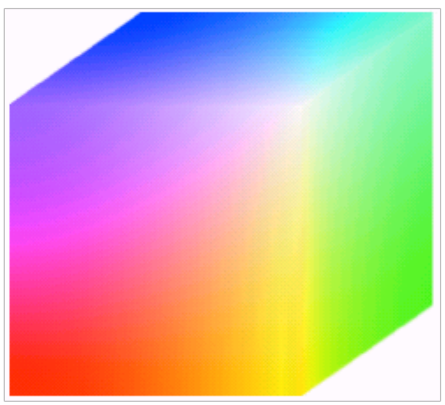
The total number of colors is 2^{24} = 16,777,216

RGB Model

a
b

FIGURE 6.9
(a) Generating the RGB image of the cross-sectional color plane $(127, G, B)$.
(b) The three hidden surface planes in the color cube of Fig. 6.8.





8 RGB 24-bit color cube.

RGB Safe Colors

Many systems today work with only 256 colors for simplicity and speed of generation.

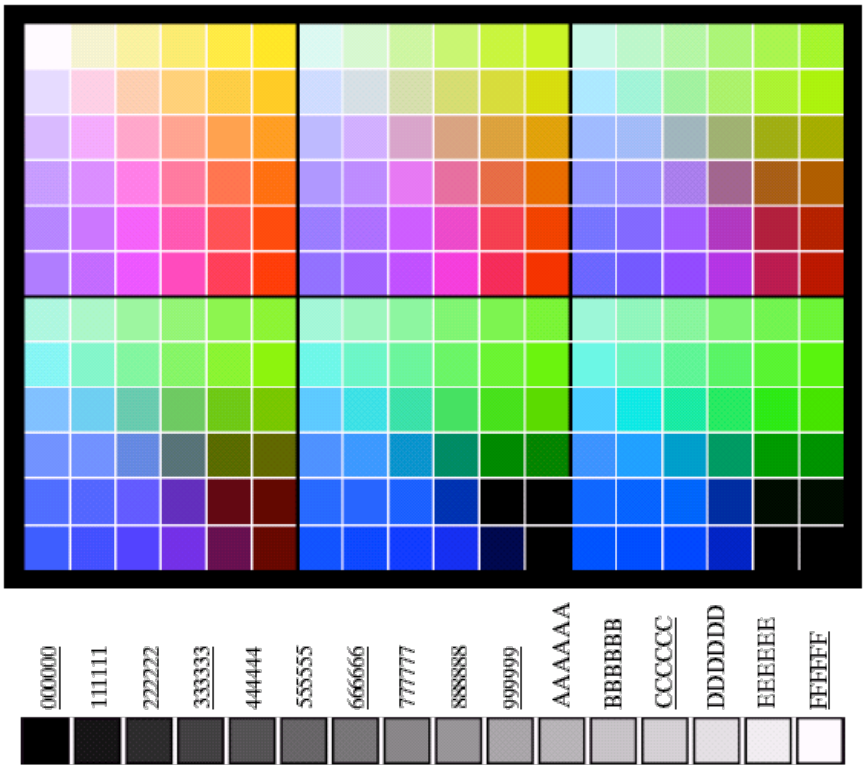
There are $6^3 = 216$ colors that can be reproduced faithfully by any system.

They use RGB values given in the table below:

Number System	Color Equivalents					
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255

TABLE 6.1 Valid values of each RGB component in a safe color.

RGB Safe Colors



a
b

FIGURE 6.10 (a) The 216 safe RGB colors. (b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

Safe colors are only on the surface!

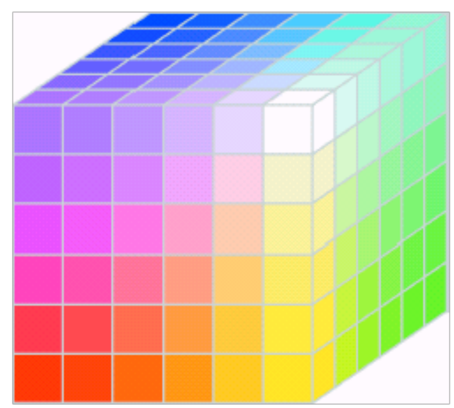


FIGURE 6.11 The RGB safe-color cube.

Examples of Safe Colors

Pure Red: FF 00 00

Black: 00 00 00

White: FF FF FF

Remember: F hex = 15 decimal = 1111 binary
FF hex = 255 decimal = 11111111 binary

CMY & CMYK Models

Cyan-Magenta-Yellow is a subtractive model which is good to model absorption of colors.

Appropriate for paper printing.

Sometimes Black is added to have CMYK

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

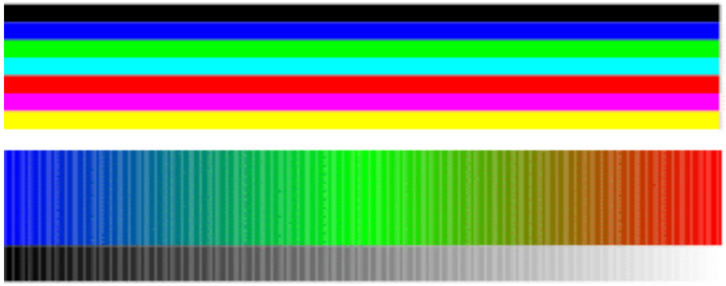
YIQ Model

Used by NTSC TV standard

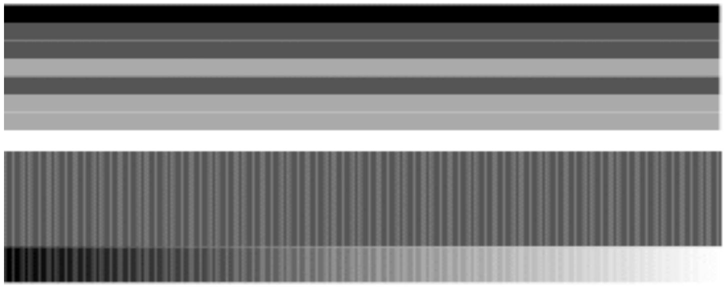
Separates Hue (I,Q) from Luminance (Y)

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.532 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

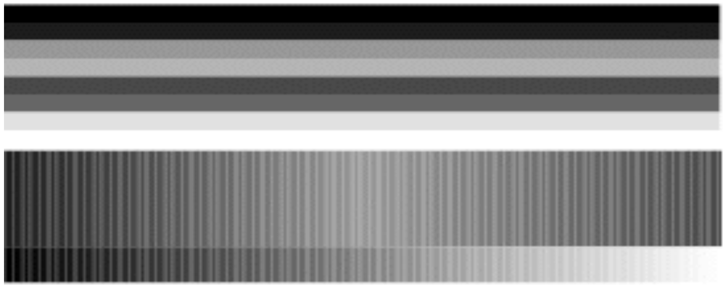
Luminance vs Intensity



(a) Colour Image



(b) Intensity Image



(c) Luminance Image

HSI Model

Humans describe color by hue, saturation and brightness

HSI (hue, saturation, intensity) decouples the intensity from the color information

HSI is ideal for image processing when color attributes are used to identify objects

RGB and HSI

- The intensity I is the (vertical) diagonal from (0,0,0) to (1,1,1)
- The saturation of these points is 0
- A plane defined by the diagonal and a cube boundary has constant hue

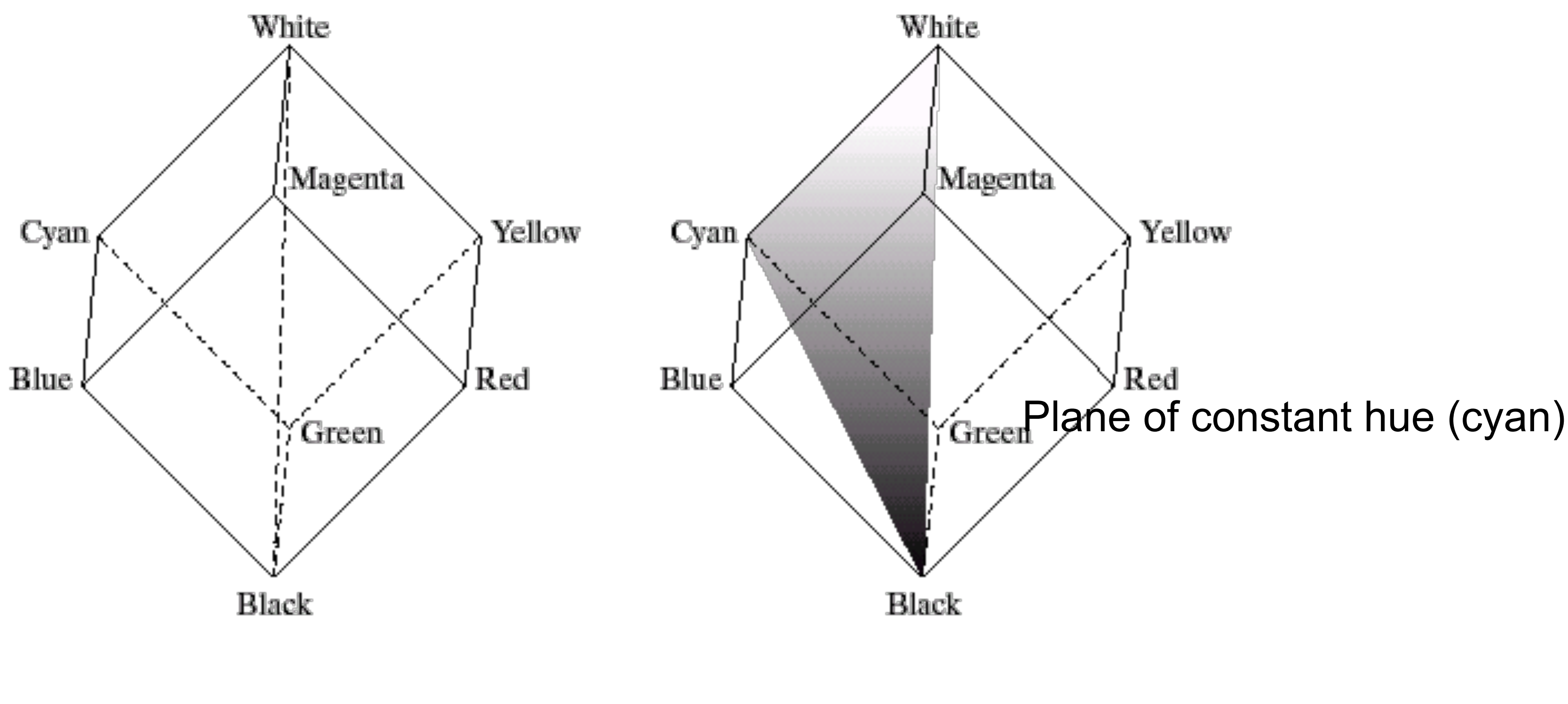


FIGURE 6.12 Conceptual relationships between the RGB and HSI color models.

HSI Model

To find the Intensity of a color within the cube:

- Find the intersection of a plane through the color point, perpendicular to the gray scale diagonal and the diagonal.
- As the plane moves up and down, (vary intensity) the intersection with the cube is a hexagon or a triangle.
- The hue is given by the angle around the diagonal
- The saturation is given by the distance to the diagonal

Simplifications of this hexagon are triangles and circles.

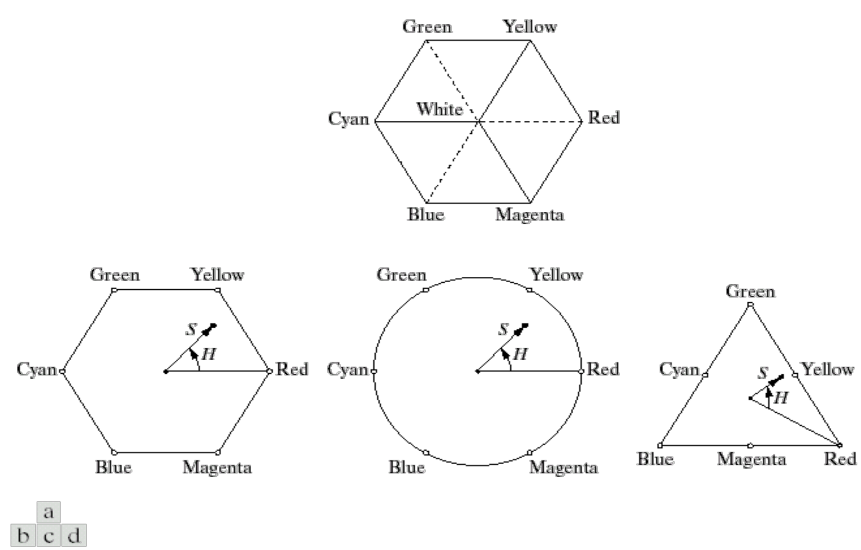
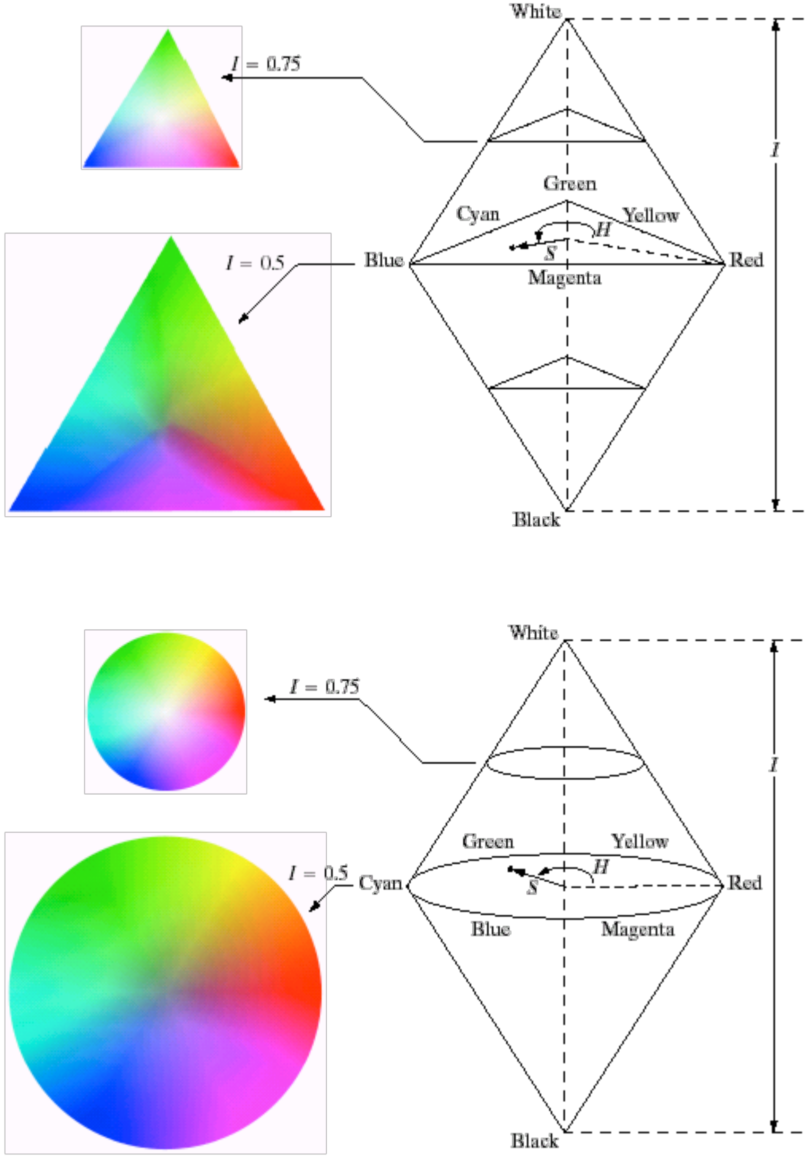


FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

HSI Model



a
b

FIGURE 6.14 The HSI color model based on (a) triangular and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.

HSI Equations

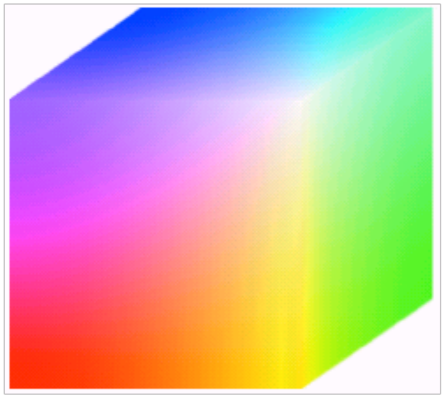
Using trigonometry:

$$H = \begin{cases} \theta & B \leq G \\ 360 - \theta & B \geq G \end{cases}$$

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}} \right\}$$

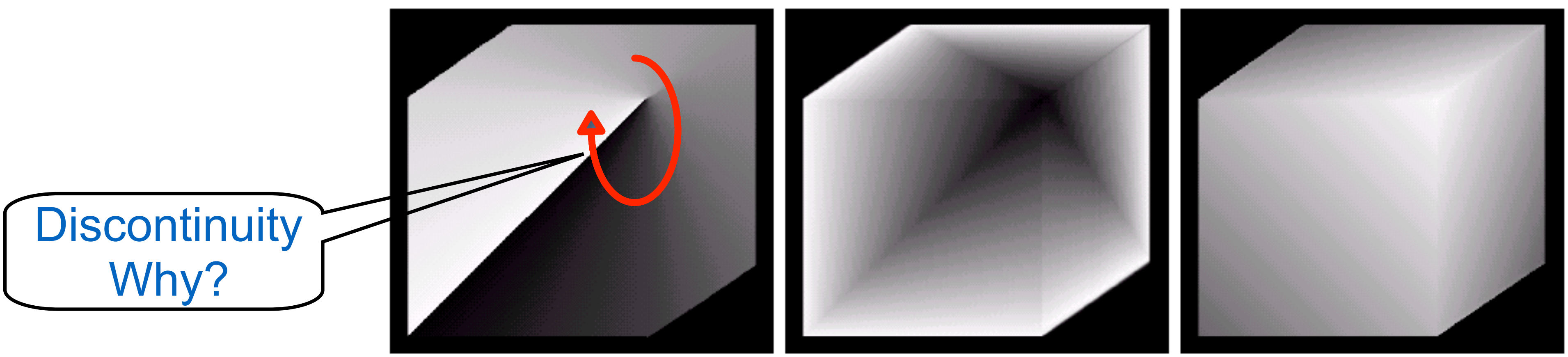
$$S = 1 - \frac{3}{(R+G+B)}\left[\min(R,G,B)\right]$$

$$I = \frac{1}{3}(R+G+B)$$



E 6.8 RGB 24-bit color cube.

HUE SAT INT.



a b c

FIGURE 6.15 HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.

CIE L*a*b*

Colorimetric:

Colors perceived as identical have identical values

Perceptually Uniform:

Color differences are perceived uniformly

Device Independent

Its gamut encompasses the entire visible spectrum

Tone and Color Corrections

Need a device-independent color model

CIE L*a*b* model:

$$L^* = 116h(Y/Y_W) - 16$$ "lightness"

$$a^* = 500\left[h(X/X_w) - h(Y/Y_W)\right]$$ "R-G"

$$b^* = 200\left[h(Y/Y_W) - h(Z/Z_W)\right]$$ "G-B"

$$h(q) = \begin{cases} \sqrt[3]{q} & q > 0.008856 \\ 7.787q + 16/116 & q \leq 0.008856 \end{cases}$$

Xw ,Yw, Zw: white reference (x=0.3127,y=0.3290)

X,Y,Z: RGB components

Pseudocolor Image Processing

Assign color (false color) to gray values using a given criterion.

Intensity slicing is one of the simplest methods.

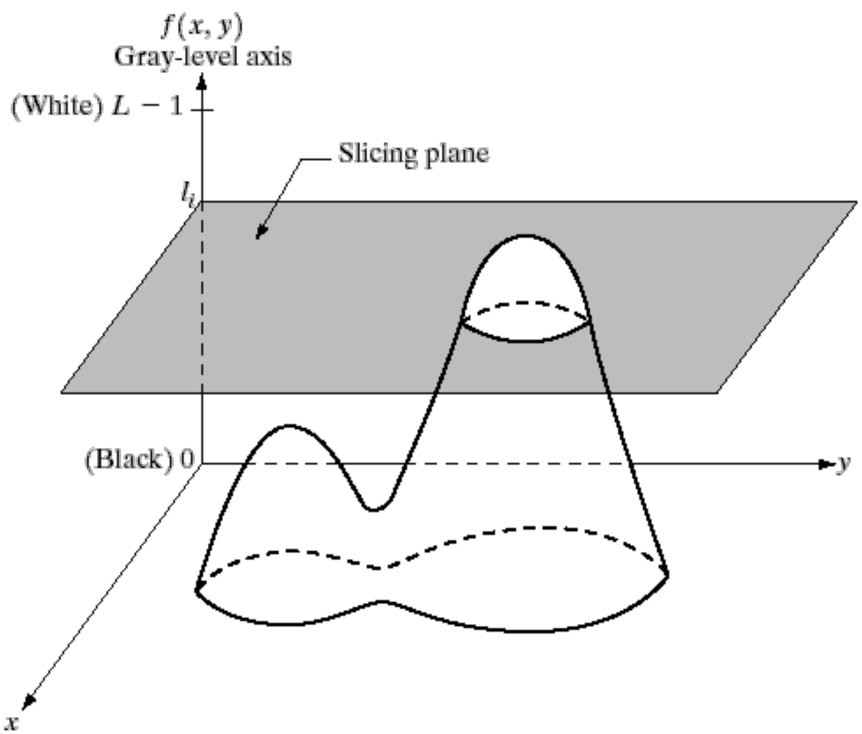
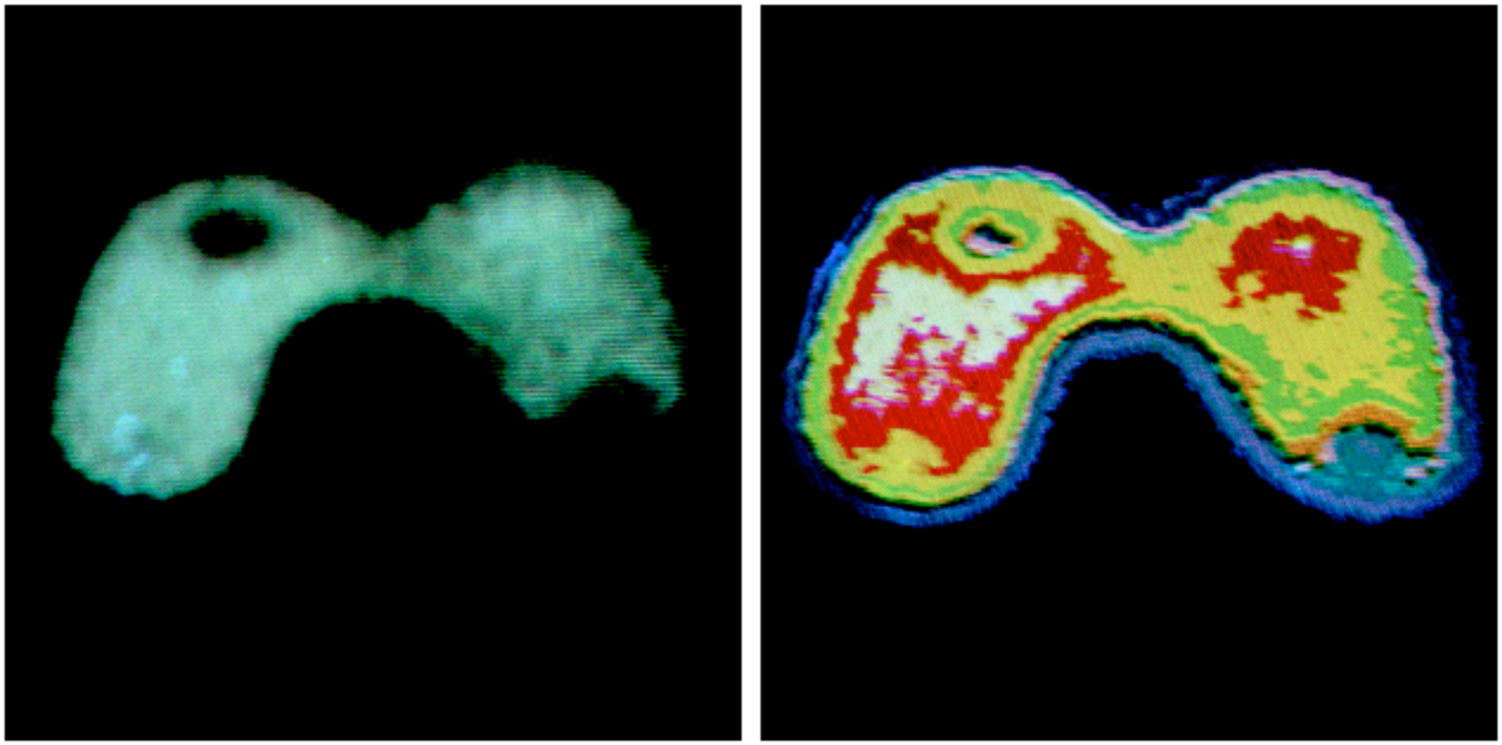


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

One color to the gray levels above the plane and another color for the levels below the plane.

Pseudocolor Examples



a b

FIGURE 6.20 (a) Monochrome image of the Picker Thyroid Phantom. (b) Result of density slicing into eight colors. (Courtesy of Dr. J. L. Blankenship, Instrumentation and Controls Division, Oak Ridge National Laboratory.)

Pseudocolor Examples

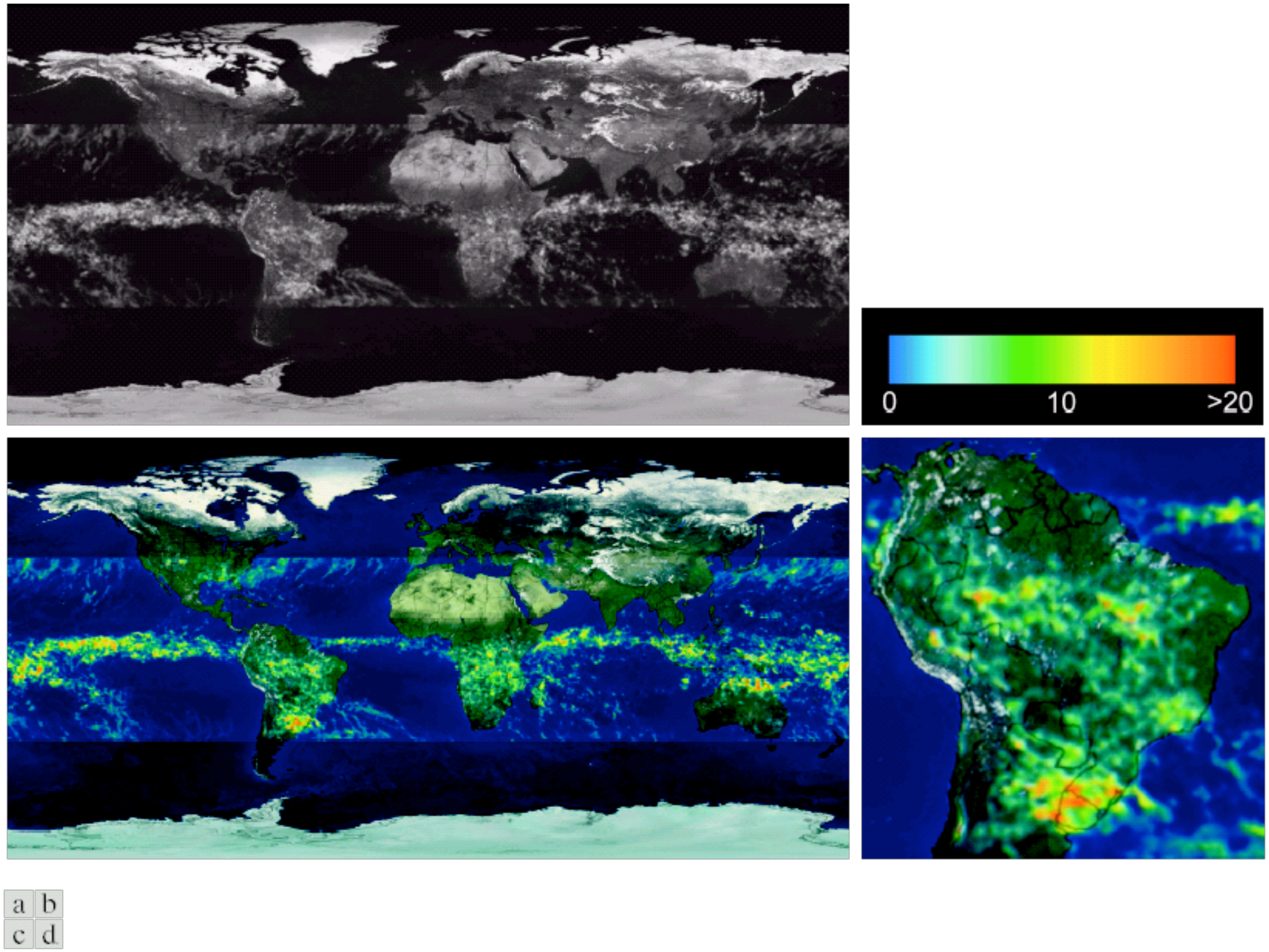


FIGURE 6.22 (a) Gray-scale image in which intensity (in the lighter horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South America region. (Courtesy of NASA.)

Gray level to color transf.

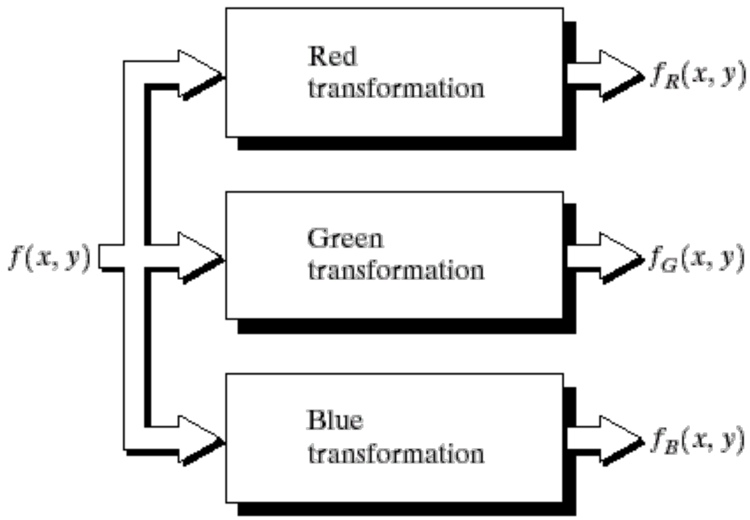
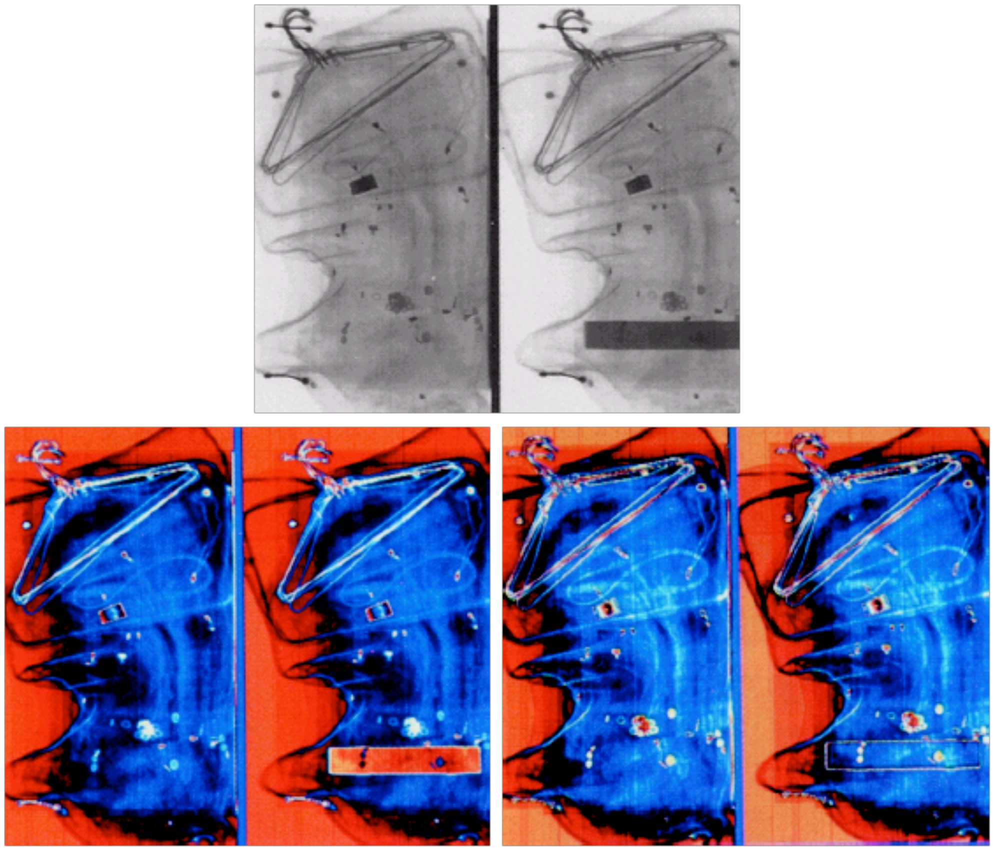


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

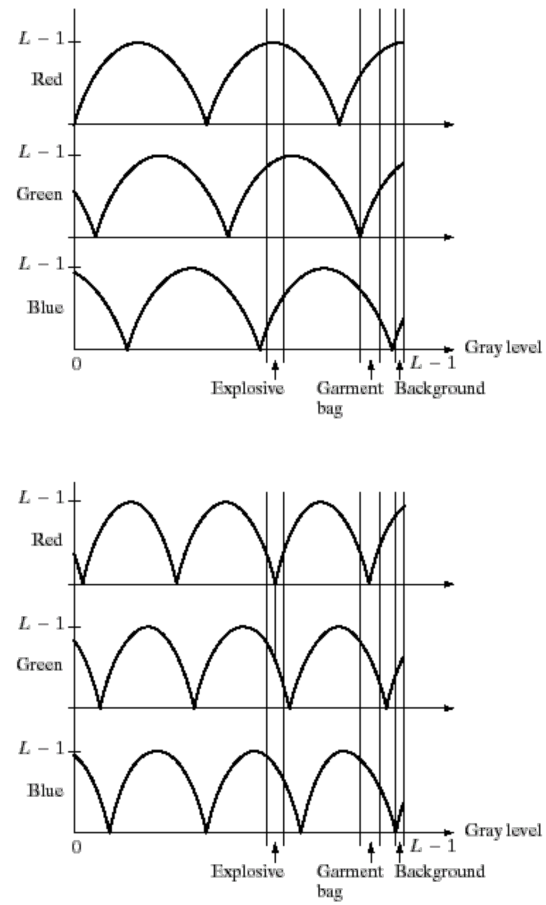
Use three functions at each pixel to drive the RGB channels

Examples



a
b c

FIGURE 6.24 Pseudocolor enhancement by using the gray-level to color transformations in Fig. 6.25. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)



a
b

FIGURE 6.25 Transformation functions used to obtain the images in Fig. 6.24.

Combination of several images

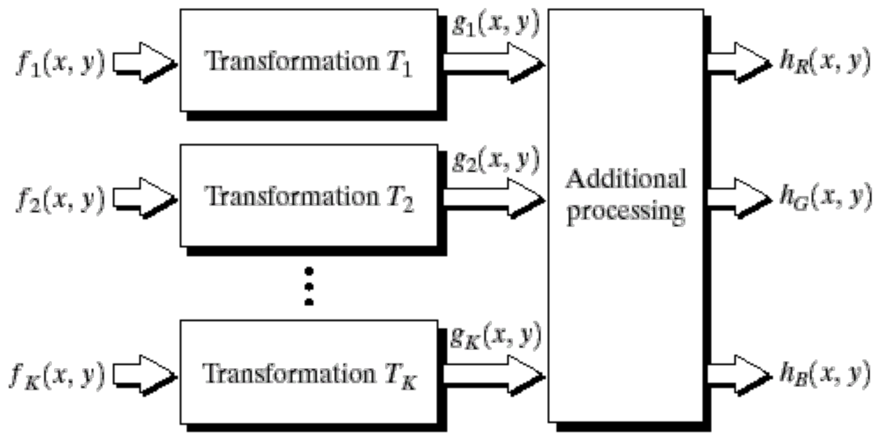


FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

Combination of several images

Visible red

green

blue

Near Infrared

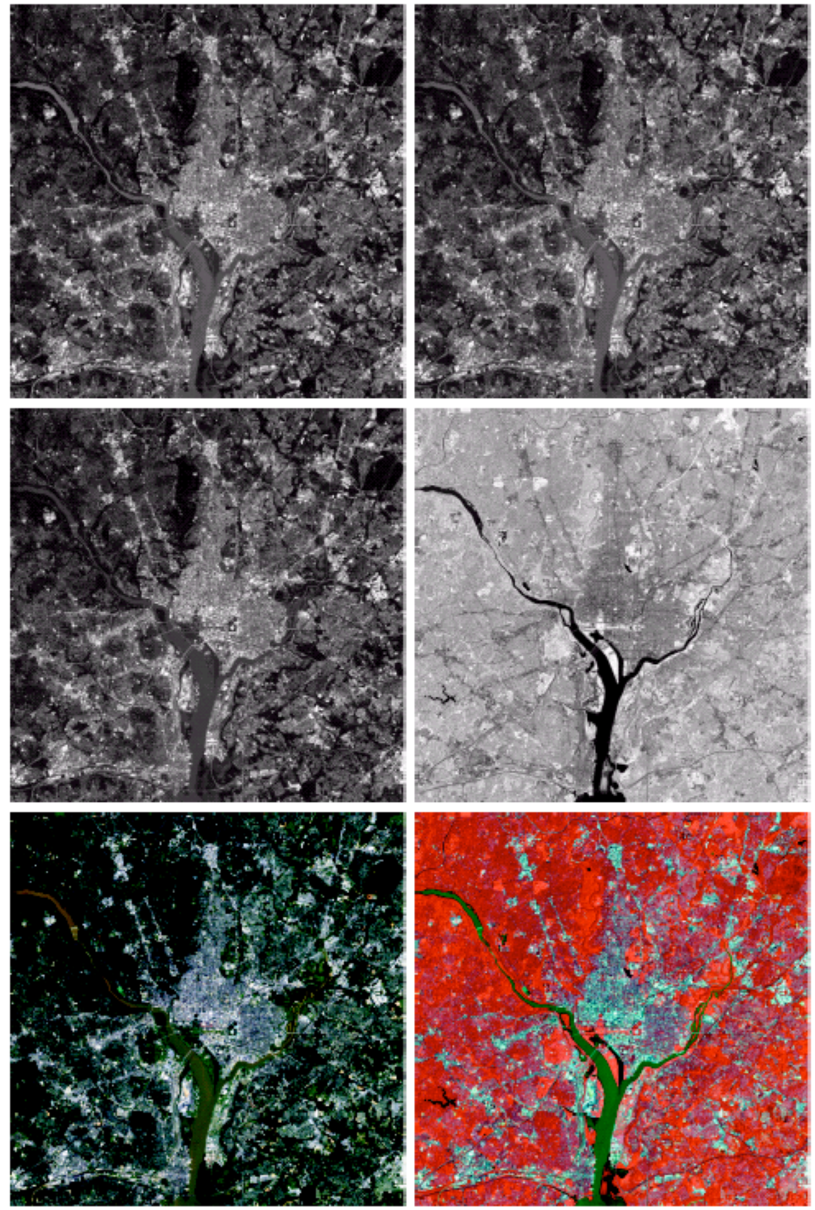


FIGURE 6.27 (a)–(d) Images in bands 1–4 in Fig. 1.10 (see Table 1.1). (e) Color composite image obtained by treating (a), (b), and (c) as the red, green, blue components of an RGB image. (f) Image obtained in the same manner, but using in the red channel the near-infrared image in (d). (Original multispectral images courtesy of NASA.)

Full Color Image Processing

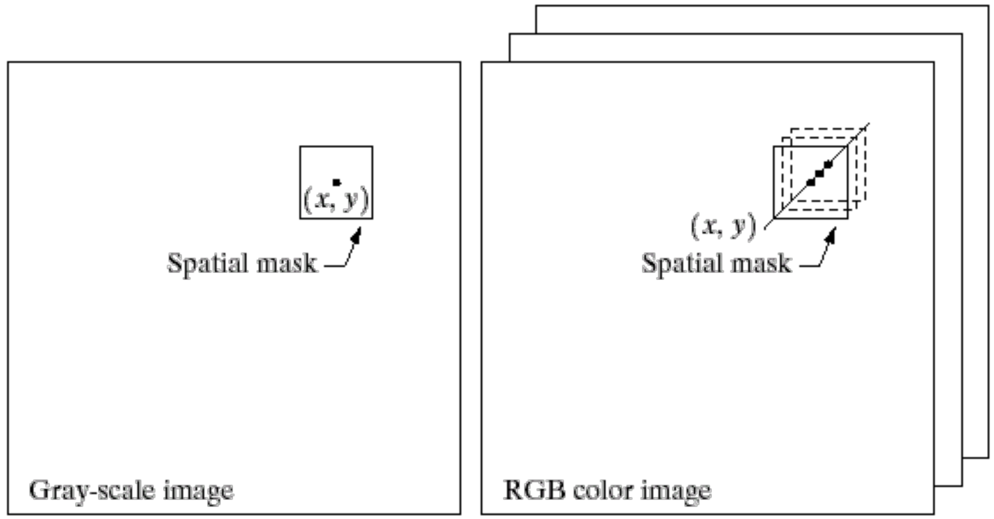
There are 2 approaches:

1. Process each component separately, then form a composite processed color image from the components.
2. Work with color pixels directly.

Basic Color Image Processing

a b

FIGURE 6.29 Spatial masks for gray-scale and RGB color images.



Pixels are VECTORS. The dimension of the vector is the number of bands

Pixels


Full color
Cyan
Magenta
Yellow
Black
Red
Green
Blue
Hue
Saturation
Intensity